UNCLASSIFIED

AD NUMBER
AD902385
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; DEC 1971. Other requests shall be referred to Air Force Armament Lab., Eglin AFB, FL.**
AUTHORITY
USADTC ltr 1 Oct 1980

THIS PAGE IS UNCLASSIFIED

F22176
72-0965

AFATL-TR-71-164

1972-0965

72-0965

AD 902 385

F22176

PERFORMANCE OF 20MM ABLATIVE AMMUNITION

2

CORNELL AERONAUTICAL LABORATORY, INC.

TECHNICAL REPORT AFATL-TR-71-164

DECEMBER 1971

Distribution Statement A:
Approved for public release;
distribution is unlimited.

NOV 2 - 1972

~~Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied December 1971. Other requests for this document must be referred to the Air Force Armament Laboratory (DLDG), Eglin Air Force Base, Florida 32542.~~

AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

Citation Format: Full Citation (1F)

Accession Number:
AD0902385
Citation Status:
Active
Citation Classification:
Unclassified
SBI Site Holding Symbol:
ATL
Fields and Groups:
190100 - Ammunition and Explosives
191000 - Ballistics
Corporate Author:
CORNELL AERONAUTICAL LAB INC BUFFALO NY
Unclassified Title:
(U) Performance of 20mm Ablative Ammunition.
Title Classification:
Unclassified
Descriptive Note:
Final rept. Sep 70-Dec 71,
Personal Author(s):
Brown, W R
Fisher, E B
Sudlik, D J
Vassallo, F A
Report Date:
Dec 1971
Media Count:
85 Page(s)
Cost:
$9.60
Contract Number:
F08635-70-C-0119
Report Number(s):
CAL-GM-3010-D-1
AFATL-TR-71-164
Project Number:
AF-670A
Task Number:
10
Monitor Acronym:
AFATL
Monitor Series:
TR-71-164
Report Classification:

Unclassified

Descriptors:

(U) (*GUN BARRELS, EROSION), (*PROJECTILES, ABLATION), SMALL ARMS AMMUNITION, SILICONES, HEAT, THERMAL INSULATION, COOLING, GUN COMPONENTS, COOK OFF, YAW, COPPER COATINGS, CYCLIC RATE, INTERIOR BALLISTICS, CARTRIDGES

Identifiers:

(U) 20-MM PROJECTILES, GATLING GUNS, M-39 GUNS(20-MM), *M-55A2 CARTRIDGES (20-MM), M-61 GUNS(20MM), SILICONE/DIMETHYL.

Identifier Classification:

Unclassified

Abstract:

(U) M55 A2, 20mm ammunition was modified by placing five cubic centimeters of gelled dimethyl silicone compound between the propellant charge and the projectile. The function of the silicone was to reduce barrel heating and erosion by coating the bore surface, forming an insulative and ablative shield against the hot propellant gases. Several thousand silicone-modified and standard rounds were fired in thermocouple-instrumented M39 and M61 (Vulcan) cannons. Very substantial reductions in heat input to the revolving drum of the M39 and the rear portion of the M61 barrel were effected, and cook-off analyses indicated a 100-percent increases in the burst length safe against cook-off in both the M39 and the M61. Erosion reduction and yaw-life increase were demonstrated in 250-round burst firing of the M39. In the M61 barrels, which were unplated, heavy coppering deposits with the modified ammunition and barrel bending interfered with rational erosion testing, but bore enlargement near the origin of rifling was decreased by the modified ammunition. Eroded and coppered barrels were sectioned and examined by metallographic and electron microprobe techniques. Ballistic performance was maintained in the modified ammunition and no failures or gun stoppages attributable to the ammunition were experienced. (Author)

Abstract Classification:

Unclassified

Distribution Limitation(s):

01 - APPROVED FOR PUBLIC RELEASE

Source Serial:

F

Source Code:

098300

Document Location:

DTIC AND NTIS

Change Authority:

ST-A PER USADTC LTR, 1 OCT 80

Performance Of

20MM Ablative Ammunition

W.R. Brown

E.B. Fisher

D.J. Sudlik

F.A. Vassallo

FOREWORD

This report covers work accomplished during the period September 1970 to December 1971 by Cornell Aeronautical Laboratory, Inc., Buffalo, New York 14221, under contract No. F08635-70-C-0119 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. Program monitors for the Armament Laboratory were Captain James D. Ingram (DLDG), Mr. David G. Uhrig (DLDG), and Mr. Ralph E. Blair (DLDG).

At Cornell Aeronautical Laboratory the work was conducted under the technical supervision of Mr. Gerald A. Sterbutzel of the Systems Research Department. CAL No. GM-3010-D-1 was assigned to this report.

The aid of Messrs. A.K. Ashby, C.M. Bork, J.J. Sisti, W.A. Stephen, and J.A. Weibel in conducting the tests is gratefully acknowledged.

This technical report has been reviewed and is approved.

LEMUEL D. HORTON, Colonel, USAF
Chief, Guns and Rockets Division

ABSTRACT

M55 A2, 20mm ammunition was modified by placing five cubic centimeters of gelled dimethyl silicone compound between the propellant charge and the projectile. The function of the silicone was to reduce barrel heating and erosion by coating the bore surface, forming an insulative and ablative shield against the hot propellant gases. Several thousand silicone-modified and standard rounds were fired in thermocouple-instrumented M39 and M61 (Vulcan) cannons. Very substantial reductions in heat input to the revolving drum of the M39 and the rear portion of the M61 barrel were effected, and cook-off analyses indicated a 100-percent increase in the burst length safe against cook-off in both the M39 and the M61. Erosion reduction and yaw-life increases were demonstrated in 250-round burst firing of the M39. In the M61 barrels which were unplated, coppering deposits with the modified ammunition interfered with rational erosion testing, but bore enlargement near the origin of rifling was decreased by the modified ammunition. Eroded and coppered barrels were sectioned and examined by metallographic and electron microprobe techniques. Ballistic performance was maintained in the modified ammunition, and no failures or gun stoppages attributable to the ammunition were experienced.

Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied December 1971. Other requests for this document must be referred to the Air Force Armament Laboratory (DLDG), Eglin Air Force Base, Florida 32542.

(The reverse of this page is blank.)

TABLE OF CONTENTS

Section		Page
I	INTRODUCTION	1
II	AMMUNITION MODIFICATION	2
	A. Propellant Testing	2
	B. Silicone Material Selection	4
	C. Extreme Temperature Testing	10
	D. Cool Propellant Tests	10
	E. Ammunition Assembly	12
III	EROSION MEASUREMENT PROCEDURES	15
	A. Erosion Measurement	15
	B. Yaw Measurement	15
	C. Velocity Measurement	15
IV	M39 TESTS	17
	A. Firing Schedule Selection	17
	B. M39 Erosion Data	19
	C. Temperature Instrumentation	23
	D. Temperature Data	27
V	M61 TESTS	34
	A. Firing Schedule Selection	34
	B. Gun and Installation	34
	C. Erosion Data	38
	D. Temperature Instrumentation	43
	E. Temperature Data	43
VI	COOK-OFF PERFORMANCE	51
	A. M39 Gun	51
	B. M61 Gun	53
VII	SUMMARY AND CONCLUSIONS	56
	APPENDIX I	59
	REFERENCES	75

LIST OF FIGURES

Figure	Title	Page
1	Single-Shot M61 Barrel Thermocouple Stations	6
2	Typical Pressure-Time Data	8
3	20mm Ablative Ammunition	9
4	Propellant Pressing	13
5	Schematic of Ablator Metering Device	14
6	20mm Bore Gauge	16
7	M39 Erosion Data From Reference 1	18
8	M39 Bore Erosion Profiles - Ablative Versus Standard Ammunition, 250 Rounds Each	21
9	M39 Breech End Bore Erosion Profiles - Ablative Versus Standard Ammunition, 250 Rounds Each	21
10	M39 Bore Erosion Profile - Ablative Ammunition	22
11	In-Wall Thermocouple Stations in the M39 Barrel	24
12	In-Wall Thermocouple Detail	25
13(A)	In-Wall Thermocouple Locations in the M39 Drum	26
13(B)	M39 Drum Showing Thermocouples and Contactor	26
14	M39 Drum Temperatures After 250-Round Burst	28
15	M39 Drum Temperatures After 150-Round Burst of Standard Ammunition	29
16	M39 Barrel Temperatures in 250-Round Burst	30
17	M39 Barrel Temperatures in 250-Round Burst	31
18	M39 Barrel Temperatures in 250-Round Burst	32
19	M39 Barrel Temperatures in 250-Round Burst	33
20	M61 Test Set-up	35
21	Schematic Diagram of M61 Ammunition Feed System	37

LIST OF FIGURES (Cont.)

Figure	Title	Page
22	M61 Erosion Profiles - Land Diameter	41
23	M61 Erosion Profiles - Groove Diameter.	42
24	M61 Barrel Thermocouple Stations	44
25	Measured M61 Barrel Temperatures 5 Inches From the Breech	45
26	Measured M61 Barrel Temperatures 10 Inches From the Breech	46
27	Measured M61 Barrel Temperatures 18 Inches From the Breech	47
28	Measured M61 Barrel Temperatures 35.5 Inches From the Breech	48
29	Measured M61 Barrel Temperatures 48 Inches From the Breech	49
30	Variations of Temperature Along the Length of a Barrel	50
31	Barrel Temperatures at 5 Inches From the Breech Showing Cook-Off Limits	54
I-1	M61 Barrel Section Locations	60
I-2	M61 Bore Surface In New Condition (8X)	61
I-3	M39 Bore Surface In New Condition (8X)	61
I-4	Section A-A, M61 Barrel No. 10, Standard Ammunition (8X)	62
I-5	Section A-A, Barrel No. 10, Standard Ammunition (50X)	62
I-6	Section A-A, Barrel No. 10, Standard Ammunition (50X)	63
I-7	Area Outlined In Fig. I-6, (325X)	63
I-8	Copper Microprobe Image Of Area Of Fig. I-7 (325X)	63
I-9	Silicon Microprobe Image Of Area Of Fig. I-7 (325X)	63
I-10	Section A-A, M61 Barrel No. 11, Ablative Ammunition (8X)	65

LIST OF FIGURES (Cont.)

Figure	Title	Page
I-11	Section A-A, Barrel No. 11 (50X)	65
I-12	Section A-A, Barrel No. 11, Ablative Ammunition (50X). . . .	66
I-13	Area Outlined In Fig. I-12 (325X)	66
I-14	Copper Microprobe Image Of Area Of Fig. I-13 (325X)	66
I-15	Silicon Microprobe Image Of Area Of Fig. I-13 (325X)	66
I-16	Section B-B, M61 Barrel No. 10, Standard Ammunition (8X) .	68
I-17	Section B-B, Barrel No. 10 (50X)	68
I-18	Section B-B, Barrel No. 10, Standard Ammunition (325X) . . .	69
I-19	Iron Microprobe Image Of Area Of Fig. I-18 (325X)	69
I-20	Copper Microprobe Image Of Area Of Fig. I-18 (325X)	69
I-21	Aluminum Microprobe Image Of Area Of Fig. I-18 (325X) . . .	69
I-22	Section B-B, M61 Barrel No. 11, Ablative Ammunition (8X). .	70
I-23	Section B-B, Barrel No. 11 (50X)	70
I-24	Section B-B, Barrel No. 11, Ablative Ammunition (325X) . . .	71
I-25	Copper Microprobe Image Of Area Of Fig. I-24, (325X)	71
I-26	Zinc Microprobe Image Of Area Of Fig. I-24 (325X)	71
I-27	Silicon Microprobe Image Of Area Of Fig. I-24 (325X)	71
I-28	Section A-A, M39 Barrel No. 4, Standard Ammunition (50X) .	72
I-29	Section B-B, M39 Barrel No. 4, Standard Ammunition (50X) .	72
I-30	Section Near Muzzle, M39 Barrel No. 4, Standard Ammunition (50X)	73

SECTION I

INTRODUCTION

Barrel erosion reduces the effective life of barrels in automatic weapons. Reduced erosion would result in less restriction of combat firing schedules, as well as savings in maintenance, logistic manhours, and procurement dollars.

The objective of this study was to modify standard 20mm ammunition by the addition of a silicone fluid or gel which has been proven effective in reducing erosion. Reductions in barrel temperature and erosion have been demonstrated with similar materials in 30mm and 7.62mm tests.

A three-phase study was conducted. Phase I was devoted to modification of the standard M55 A2 round to accommodate the silicone such that ballistic performance was maintained. In Phase II, 2000 modified rounds were assembled and fired in thermocouple-instrumented M39 cannon barrels to determine temperature and erosion performance. Comparative firings of standard ammunition were also conducted. Phase III consisted of the assembly and firing of 6000 modified rounds in an instrumented M61 gun. In this weapon, it was possible to simultaneously fire modified ammunition in one barrel and standard ammunition in other barrels, facilitating the acquisition of comparative data on temperature rise and erosion performance.

Other program elements included metallurgical examination of eroded barrels and the analysis of temperature data to determine cook-off characteristics and equilibrium barrel temperatures in continuous bursts.

SECTION II
AMMUNITION MODIFICATION

A. Propellant Testing

As predicted from previous studies[1], the quantity of silicone fluid or gel required in the cartridge case to reduce barrel heating and erosion in a 20mm cannon approaches 5 grams (77 grains). This volume of silicone occupies about 5 cubic centimeters. Since very little volume is left unfilled in standard M55 ammunition, experimental single-shot firing was required to determine how the propellant charge could be modified to accommodate the silicone. These firings, in an instrumented M61 barrel, were utilized also to select the most promising silicone viscosity or consistency in terms of barrel heat input reduction.

To facilitate the single-shot tests, an M61 barrel was modified with an interrupted-thread breech closure machined from steel stock and a steel strongback fitted over the chamber to insure proper holding of the Kistler piezoelectric transducer employed to measure chamber pressure. Three external thermocouples (26 gauge chromel-alumel) were welded to the barrel at points 4.75 inches, 18.0 inches, and 55.0 inches from the breech end. These stations were designated Stations 1, 2, and 3, respectively. In testing of this type, the barrel served as a simple calorimeter in which the external temperature rise measured a few seconds after firing was proportional to the heat transferred from the propellant gases to the tube.

Initial approaches to propellant volume reduction included admixtures of ball pistol powder to the conventional WC 870 ball propellant and complete substitution of several ball and IMR propellants which have greater quickness and force than does WC 870.

Baseline velocity, pressure, and tube heating data were recorded by firing several as-received rounds (type M55 A2, Lot KOP-153-5). Velocity was measured between two conductive paper grids located 15 feet and 25 feet downrange from the muzzle. As summarized in entry 10 of Table I, the average velocity of these rounds was found to be 3448 feet/second, and the average of the peak pressures was 59,880 psi. This pressure was somewhat higher than that determined for other 20mm ammunition lots fired in previous work at Cornell Aeronautical Laboratory but appeared to be within the specifications for this cartridge.

A mixture of 70 percent WC 870 ball and 30 percent WC 630 ball propellants was tested first. As shown by entries 11 through 14 in Table I, the velocity of standard rounds was approximated by a 533-grain charge of this mixture, with a peak pressure of 76,000 psi. The empty volume in these test rounds, which amounted to more than 5 cm^3 with the 533-grain propellant charge, was filled with paper wadding. This experimental propellant charge resulted in a slight decrease in barrel heat input relative to the standard cartridge. Heat input data for these tests are not considered accurate to better than ± 5 percent.

TABLE I. SINGLE SHOT FIRING DATA

TABLE ENTRY NO.	ROUND SERIAL NO. †	PROPELLANT CHARGE TYPE AND WEIGHT	VELOCITY (FT/SEC)	PEAK PRESSURE (psi)	HEAT INPUT AS PERCENT OF STANDARD ROUNDS STA. 1	STA. 2	STA. 3
1	2	STANDARD 870 BALL, 612 GR.	3470	MISSED			
2	4	STANDARD 870 BALL, 612 GR.	MISSED	60,000			
3	5	STANDARD 870 BALL, 612 GR.	3445	62,000			
4	9	STANDARD 870 BALL, 612 GR.	3450	64,000			
5	16	STANDARD 870 BALL, 612 GR.	3480	63,000			
6	22	STANDARD 870 BALL, 612 GR.	3460	58,000			
7	35	STANDARD 870 BALL, 612 GR.	3420	55,000			
8	42	STANDARD 870 BALL, 612 GR.	3440	62,000			
9	50	STANDARD 870 BALL, 612 GR.	3420	55,000			
10		AVERAGE OF ABOVE	3448	59,880	100	100	100
11	10 THRU 12, AVE.	MIX A*, 463 GR., NO ABLATOR	3150	62,670			
12	13 THRU 15, AVE.	MIX A*, 478 GR., NO ABLATOR	3200	66,330			
13	17 & 18 AVE.	MIX A*, 509 GR., NO ABLATOR	3325	70,000			
14	19 THRU 21, AVE.	MIX A*, 533 GR., NO ABLATOR	3425	76,000	95	92	93
15	29 THRU 31, AVE.	MIX A, 533 GR., +77 GR. ABLATOR** NO DIAPHRAGM	3330	73,300	68	91	101
16	32 THRU 34, AVE.	MIX A, 533 GR., +77 GR. ABLATOR** WITH DIAPHRAGM	3395	74,700	64	94	103

† ROUND SERIAL NUMBERS NOT LISTED IN ANY TABLE REPRESENT ROUNDS NOT FIRED DUE TO ANTICIPATED HIGH PRESSURES OR ROUNDS FOR WHICH DATA WERE MISSED ON FIRING.

* MIX A IS 70% WC 870 BALL PROPELLANT +30% WC 630 P BALL PROPELLANT.

**1000 CSTKS DIMETHYL SILICONE FLUID.

Entries 15 and 16 of Table I indicate the effect of adding to the charge 77 grains of 1000 cstks viscosity dimethyl silicone, contained in a 1-mil thick polyethylene bag. With no plastic diaphragm between the fluid and propellant (entry 15), the silicone reduced velocity almost 100 feet/second, while reducing heating at Station 1 by 34 percent. With a diaphragm of 20-mil thick cellulose acetate butyrate in place (entry 16), velocity was almost restored and the heat reduction was similar. Heat inputs at all stations would be increased slightly if propellant were added to bring velocity up to the 3448 feet/second level of the standards.

Additional tests (Table II) of various ball propellant mixtures and two types of IMR propellant (Nos. 4350 and 8261) were conducted, but it was not possible to secure the required velocity in conjunction with a tolerable pressure increase. It appeared that all available propellants lacked sufficient bulk density to meet ballistic requirements.

There is a large void volume present between the grains of a loosely packed propellant, particularly when nearly spherical grains of constant size are involved. It was found that the simple expedient of compressing the conventional charge of WC 870 propellant in the case provided the required standard ballistics with 77 grains of silicone in place. Data for three uncrimped rounds are given in the last three entries of Table II.

B. Silicone Material Selection

After further preliminary testing, a final test of three gelled or thickened silicone compositions in conjunction with compacted propellant was conducted. The single-shot M61 barrel was fitted with five thermocouples as shown in Figure 1. All tests employed Lot LC-24-345 ammunition or modified rounds made with propellant and components from disassembled rounds of that lot.

Lot LC-24-345 rounds yielded desirably low peak pressures (Table III and Figure 2) both as-received and modified with silicone gel. Pressures were under 60,000 psi and velocities were acceptable. Heating reductions were substantial at barrel Stations 1 and 2 and modest at Station 3, 18 inches from the breech end.

On the basis of the results contained in Table III, the composition consisting of 95 percent dimethyl silicone of 100,000 cstks viscosity and 5.0 percent Cabosil was selected as most effective.

A test of several days' duration of rounds assembled with diaphragms showed negligible flow of gelled ablator past the diaphragm. Furnace tests at temperatures up to 200°F indicated that this composition would not flow in the case due to gravity or to any surface wetting and spreading forces which might arise in the case/propellant materials system. In fact, the gelled fluid did not move downward in a capillary space formed between two strips of brass held at 200°F. In view of these findings, it was possible to dispense with rubber capsules and rely on a flat plastic diaphragm to isolate the silicone gel from the propellant. The selected configuration is shown in Figure 3.

Table II. SINGLE-SHOT FIRING DATA

TABLE ENTRY NO.	ROUND SERIAL NOS.	PROPELLANT CHARGE TYPE AND WEIGHT	VELOCITY (ft/sec)	PEAK PRESSURE (psi)
1	AVE. OF 9	612 GR. STANDARD 870 BALL	3448	59,900
2	32 THRU 34, AVE.	533 GR. MIX A* + 77 GR. ABLATOR**	3395	74,700
3	65-67 & 73-77, AVE.	STANDARD CHARGE, UNCRIMPED	3369	51,000
4	89	503 GR. IMR 9350, UNCRIMPED	3415	82,000
5	90 & 91, AVE.	494 GR. IMR 8261, UNCRIMPED	3260	68,000
6	93 & 94, AVE.	525 GR. IMR 8261, UNCRIMPED	3380	73,000
7	95 & 96, AVE.	533 GR. IMR 8261, UNCRIMPED	3410	75,500
8	104 COMPACTED	612 GR. 870 BALL + 77 GR. ABLATOR	3345	59,000
9	105 COMPACTED	612 GR. 870 BALL + 77 GR. ABLATOR	3360	58,000
10	106 COMPACTED	612 GR. 870 BALL + 77 GR. ABLATOR	3385	59,000

*MIX A IS 70% WC 870 BALL PROPELLANT + 30% WC 630P BALL PROPELLANT.

**1000 CSTKS DIMETHYL SILICONE FLUID + FUMED SILICA.

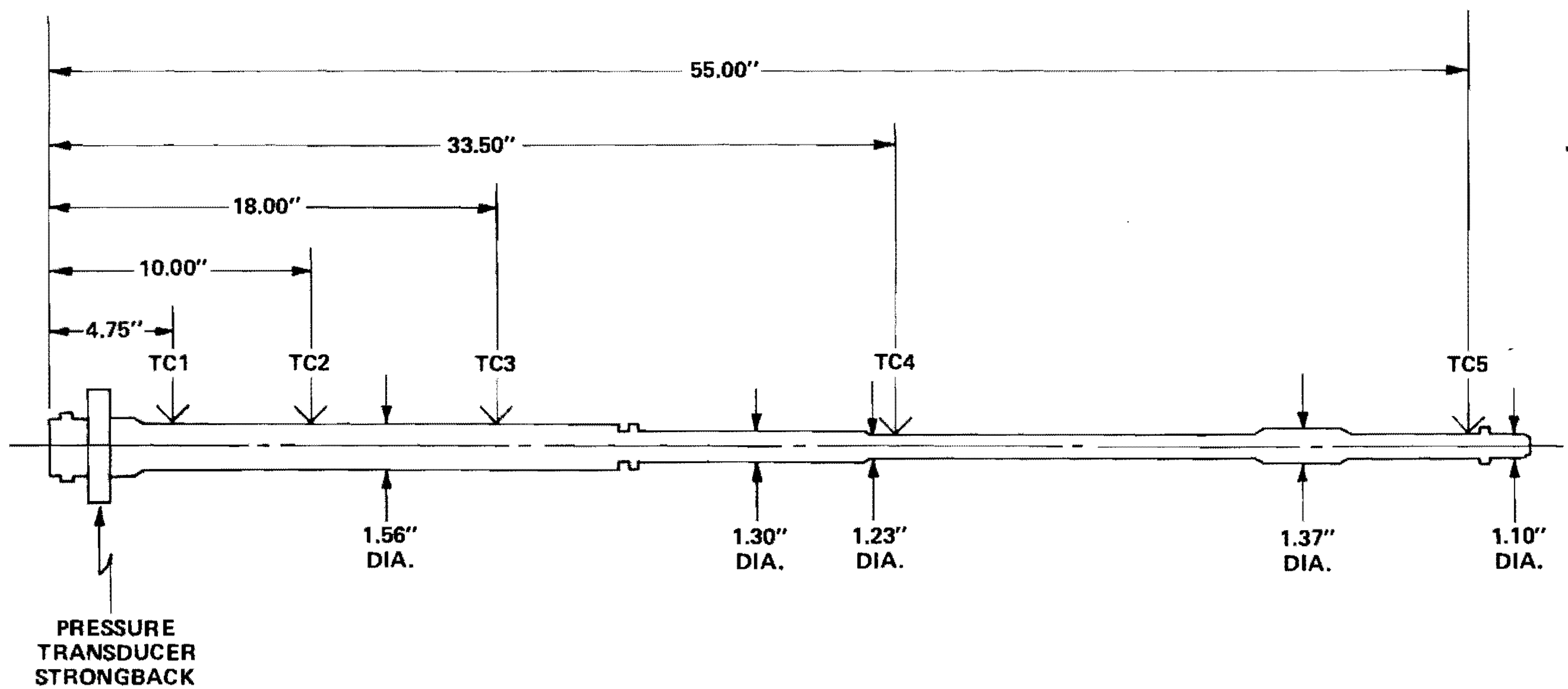


Figure 1. Single-Shot M61 Barrel Thermocouple Stations

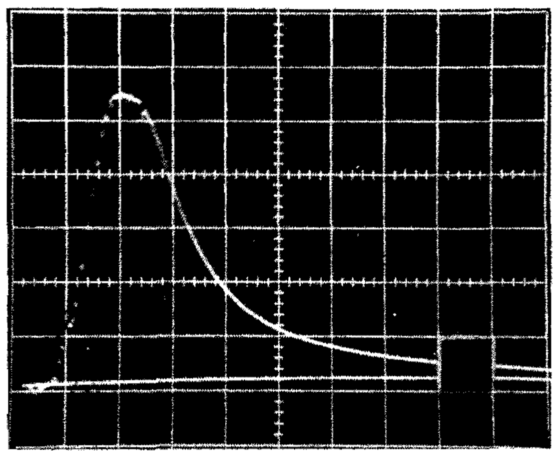
TABLE III. SINGLE SHOT FIRING DATA

TABLE ENTRY NO.	ROUND SERIAL NOS.	ROUND TYPE AND ABLATOR COMPOSITION	VELOCITY (ft/sec)	PEAK PRESSURE (psi)	HEAT INPUT AS PERCENT OF STANDARD ROUNDS, AT STATION:				
					1	2	3	4	5
1	123-126	LOT LC-24-345 STANDARDS, 622 GR. PROP. (AS RECEIVED)	3340	50,700	100	100	100	100	100
2	139-141	600 GR. COMPACTED PROP.*, GELLED 1000 CSTKS SILICONE**	3380	59,700	76	90	90	100	93
3	148-150	600 GR. COMPACTED PROP., 60,000 CSTKS. SILICONE	3380	58,300	57	75	96	96	91
4	151-153	600 GR. COMPACTED PROP., GELLED 60,000 CSTKS. SILICONE	3380	59,000	68	78	96	100	92
5	142-144	600 GR. COMPACTED PROP., 100,000 CSTKS. SILICONE	3370	57,700	76	76	85	96	90
6	145-147	600 GR. COMPACTED PROP., GELLED 100,000 CSTKS. SILICONE	3370	58,300	70	76	90	97	87

*TYPE 870 BALL PROPELLANT FROM LOT LC-24-345 ROUNDS.

**ALL ABLATIVE TESTS EMPLOY RUBBER CAPSULE AND BUTYRATE PLASTIC DIAPHRAGM BETWEEN CAPSULE AND PROPELLANT.
ABLATOR OF ENTRY 2 GELLED WITH 7% CABOSIL.
ABLATOR OF ENTRY 4 GELLED WITH 5% CABOSIL.
ABLATOR OF ENTRY 6 GELLED WITH 5% CABOSIL.

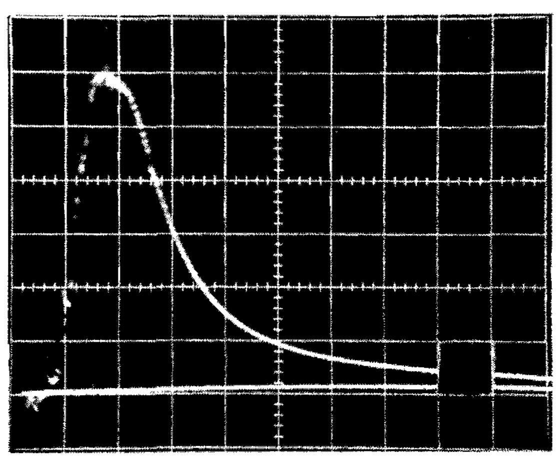
PRESSURE (10,000 PSI/LARGE DIVISION)



(TIME) 0.5 MILLISECOND/LARGE DIVISION

(A) STANDARD M55A2 ROUND, 53,000 PSI PEAK

PRESSURE (10,000 PSI/LARGE DIVISION)



(TIME) 0.5 MILLISECOND/LARGE DIVISION

(B) ABLATIVE ROUND, 58,000 PSI PEAK

Figure 2. Typical Pressure–Time Data

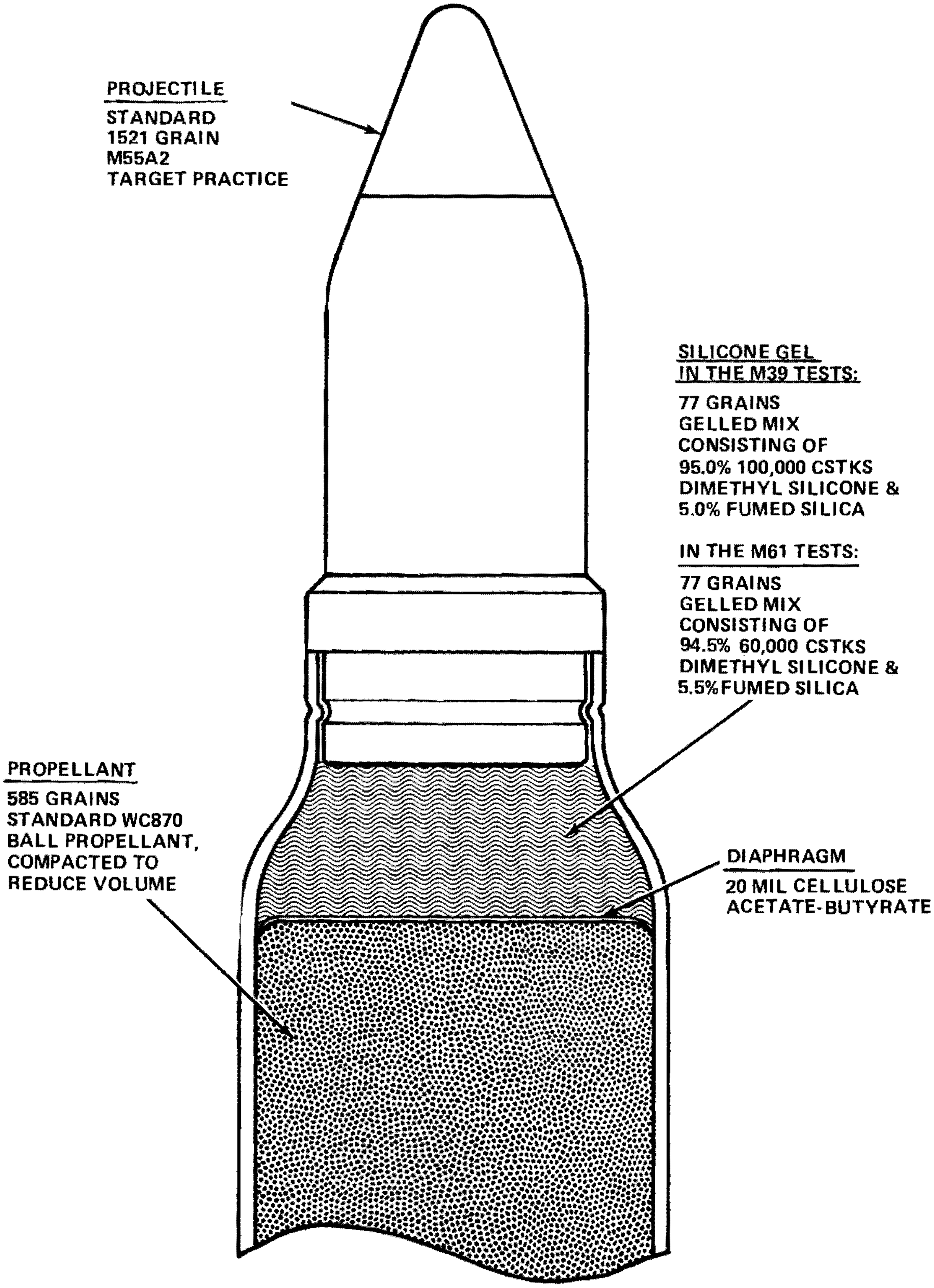


Figure 3. 20mm Ablative Ammunition

Cabosil fume silica (SiO_2) thickening agent was selected over organic agents. It was desirable to avoid the introduction of any material of low thermal stability into the silicone, which is an unusually stable, semi-organic compound.

C. Extreme Temperature Testing

Silicone-modified ammunition was tested at -65°F, 70°F, and +165°F with results as shown in Table IV. Rounds were conditioned at the specified temperatures and fired in an instrumented M61 barrel which was at room temperature. Each round was withdrawn from the oven or refrigerator and fired within seconds such that very little unwanted heating or cooling of the propellant took place. While somewhat low pressures were determined for both ablative and standard ammunition, it was clear that the ablator was very effective in reducing barrel heating at all temperatures at which ammunition is required to function.

A comparison of the average velocities of the standard and ablative rounds at 70°F indicated that a slight increase might be needed in the 600-grain propellant charge employed in ablative rounds to bring the velocity up to standard. Small charge adjustments have corresponding slight effect on peak pressure and heat input data. Table IV velocity data show that the variation in velocities over the temperature range -65 to 165°F was of the order of 200 feet/second for both standards and ablatives.

Paper witnesses placed 10 feet from the muzzle during the tests indicated very little gel droplet effluent at +165°F and 70°F and a moderate amount at -65°F. These findings were in accordance with previous tests in other calibers which indicated that droplet effluent increased with increasing ablator viscosity.

D. Cool Propellant Tests

Before proceeding with the assembly of 8000 silicone-modified rounds, brief exploratory tests of cool methyl centralite propellants were conducted in the single-shot barrel. Canadian Arsenal's lots CAZA 5256 and and 5257 were tested as-received, and the former was compacted and fired with ablator. It was found that these propellants had a bulk density roughly 5 percent less than that of WC 870 ball propellant, such that the case would accommodate only 588 grains (the usual WC 870 charge is about 617 grains). The 588-grain charge of Lot 5256 material yielded a velocity of ~3340 feet/second and substantially reduced heating in the forward half of the barrel (Table V). In conjunction with ablator, the cool propellant exhibited reduced heating throughout the barrel.

TABLE IV. ABLATOR PERFORMANCE AT EXTREME TEMPERATURES

TABLE ENTRY NO.	ROUND SERIAL NUMBERS	ROUND TYPE	ROUND TEMP.	PEAK PRESSURE (psi)	VELOCITY (ft/sec)	HEAT INPUT AS PERCENT OF STANDARD, AT STATION**			
						1	2	4	5
1	123-126, 209, 227-232	STANDARDS, LOT. LC-24-345 (AS RECEIVED)	70°F	50,200	3370	100	100	100	100
2	238-242	STANDARDS, LOT. LC-24-345 (AS RECEIVED)	+165°F	54,000	3460	***			
3	248-252	STANDARDS, LOT. LC-24-345 (AS RECEIVED)	− 65°F	47,000	3250				
4	233-237	ABLATIVES, 600 GR. PROP., GELLED SILICONE*	70°F	47,000	3350	64	67	97	95
5	243-247	ABLATIVES, 600 GR. PROP., GELLED SILICONE*	+165°F	51,500	3390	63	72	96	93
6	210-214, 253-254	ABLATIVES, 600 GR. PROP., GELLED SILICONE*	− 65°F	51,000	3190	72	88	96	92

* 600 GR. 870 BALL PROPELLANT FROM LOT. LC-24-345 ROUNDS, 77 GR. 100,000 cstk. SILICONE CONTAINING 5% FUME SILICA, ISOLATED BY BUTYRATE DIAPHRAGM.

** BARREL STATIONS AS SHOWN IN FIG. 1.- STATION 3 DATA (DELETED) WAS IN ERROR.

*** BARREL HEATING DATA FOR STANDARD ROUNDS WERE THE SAME AT ALL TEMPERATURES, WITHIN EXPERIMENTAL ACCURACY

TABLE V. COOL PROPELLANT DATA

Round Type	Avg. Vel. (ft/sec)	Peak Pres. (psi)	Relative Heat Inputs at Stations: 1	2	3	4	5
Std.	3370	50-52,000	100	100	100	100	100
CAZA 5256	3340	~58,000	98	96	91	89	84
CAZA 5256 + Ablator	3260	~58,000	44	72	93	89	77

While the velocity with ablator was too low (about 110 feet/second below standard), it was clear that the combination of methyl centralite propellant and ablator was promising and deserving of further study in the future.

E. Ammunition Assembly

Three operations (in addition to those common to conventional ammunition assembly) were required to assemble the silicone-modified rounds. Propellant compaction was accomplished in a small hydraulic press by slowly driving a plunger into the charge as shown in Figure 4. No support was required around the case at the pressure employed.

After pressing, the cellulose acetate-butyrate diaphragm was pushed into place over the charge. The diaphragm, punched from sheet stock, was made 0.99 inch in diameter to fit snugly in the case.

Silicone gel was dispensed into each round from an air-operated device as shown in Figure 5. The quantity charged was 77 ±2 grains.

Of the over 8000 modified rounds assembled for the program, 6000 were made from complete rounds disassembled at CAL. A projectile-pulling tool was fabricated to facilitate disassembly.

The source of the dimethyl silicone fluid employed in the test rounds was the Dow Corning Corporation, Midland, Michigan. All of the fluids tested meet Military Specification MIL-S-21568A. The fume silica was Cabosil grade M-5 from the Cabot Corporation, Boston, Massachusetts.

As noted in Figure 3, 60,000 cstks dimethyl silicone was employed in the 6000 rounds assembled for the M61 firings. The change to 60,000 cstks silicone from 100,000 cstks silicone was made when it was learned that a 30 percent cost reduction could be effected. It was estimated that, in mass production, the silicone material cost per round would be roughly 1 cent.

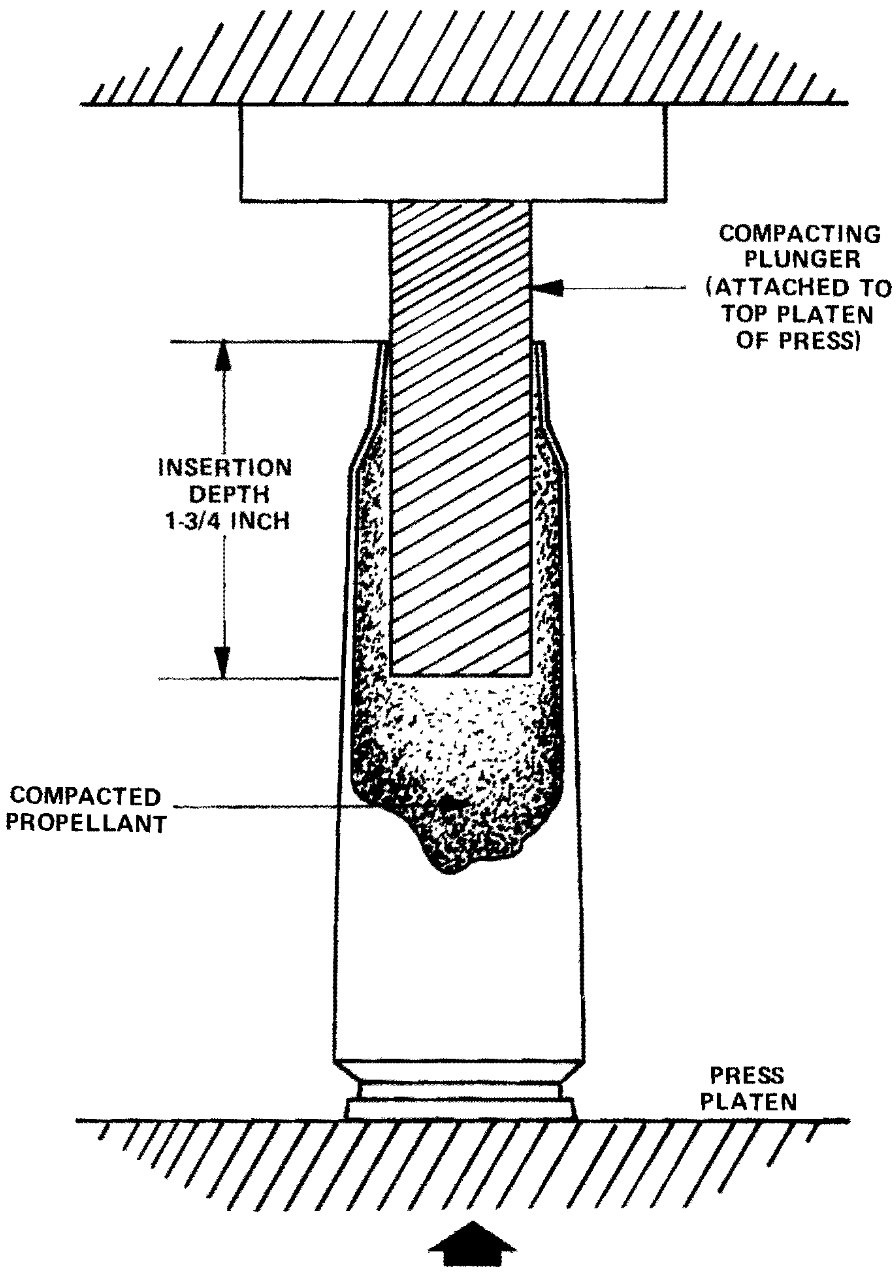


Figure 4. Propellant Pressing

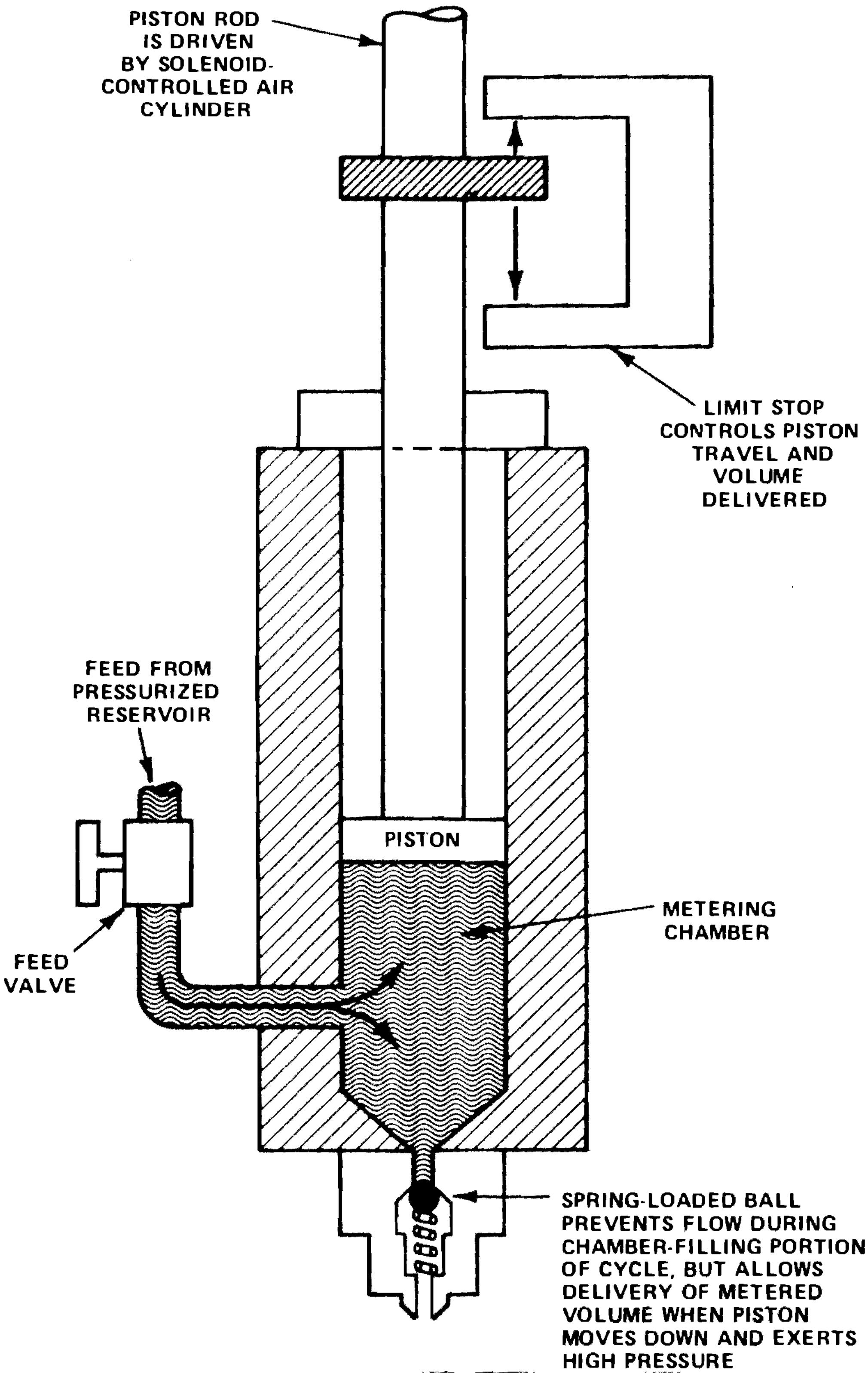


Figure 5. Schematic of Ablator Metering Device.

SECTION III

EROSION MEASUREMENT PROCEDURES

A. Erosion Measurement

Measurements of land and groove erosion were accomplished with a Brown and Sharpe Intrimik micrometer gage, specially adapted to measure the inside diameter of the M39 and M61 barrels. The gage was fitted with a 5-foot extension rod between the gage head and micrometer scale, as shown in Figure 6. The three measuring pins of the gage head were machined to the rifling groove width to permit groove diameter measurement. For measurement of the land diameter, the measuring pins were retracted, and a guide pin was inserted into the gage head such that the measuring pins ride on three rifling lands 120 degrees apart. The guide pin also allows for the measurement of the same lands throughout the barrel length by preventing the gage from turning freely in the barrel.

Further study of the eroded bores was accomplished by making rubber impressions periodically during the tests. These impressions were made using General Electric RTV-30 Silicone Rubber Compound.

M39 and M61 barrels fired to failure were sectioned and subjected to metallographic and electron microprobe examination. The results of these studies are reported in Appendix I.

B. Yaw Measurement

Barrels were considered to have reached yaw failure when 20 percent or more of a 40-round series exhibited yaw of 15 degrees or more. Yaw detection during burst firing was accomplished with a moving target at ~1000 inches. The target consisted of a 24-inch wide roll of 6-mil polyethylene. Target speed was varied to accommodate the differing firing rates of the M39 and M61. The plastic film was found to have superior ability to withstand the pressure forces of firing and good tear resistance when rounds struck near one another. A stationary witness plate was also placed to determine dispersion during each burst.

For cold yaw determination after each burst test, a series of single shots was fired in each barrel (after cooling) and a group of stationary witness plates was placed at intervals down range.

C. Velocity Measurement

Single-shot velocity measurements were made in all new barrels and upon cooling after each significant burst firing. Conductive paper screens were positioned 10 and 20 feet from the muzzle. Time-of-flight was measured with two Berkley EPUT counters in parallel for redundancy.

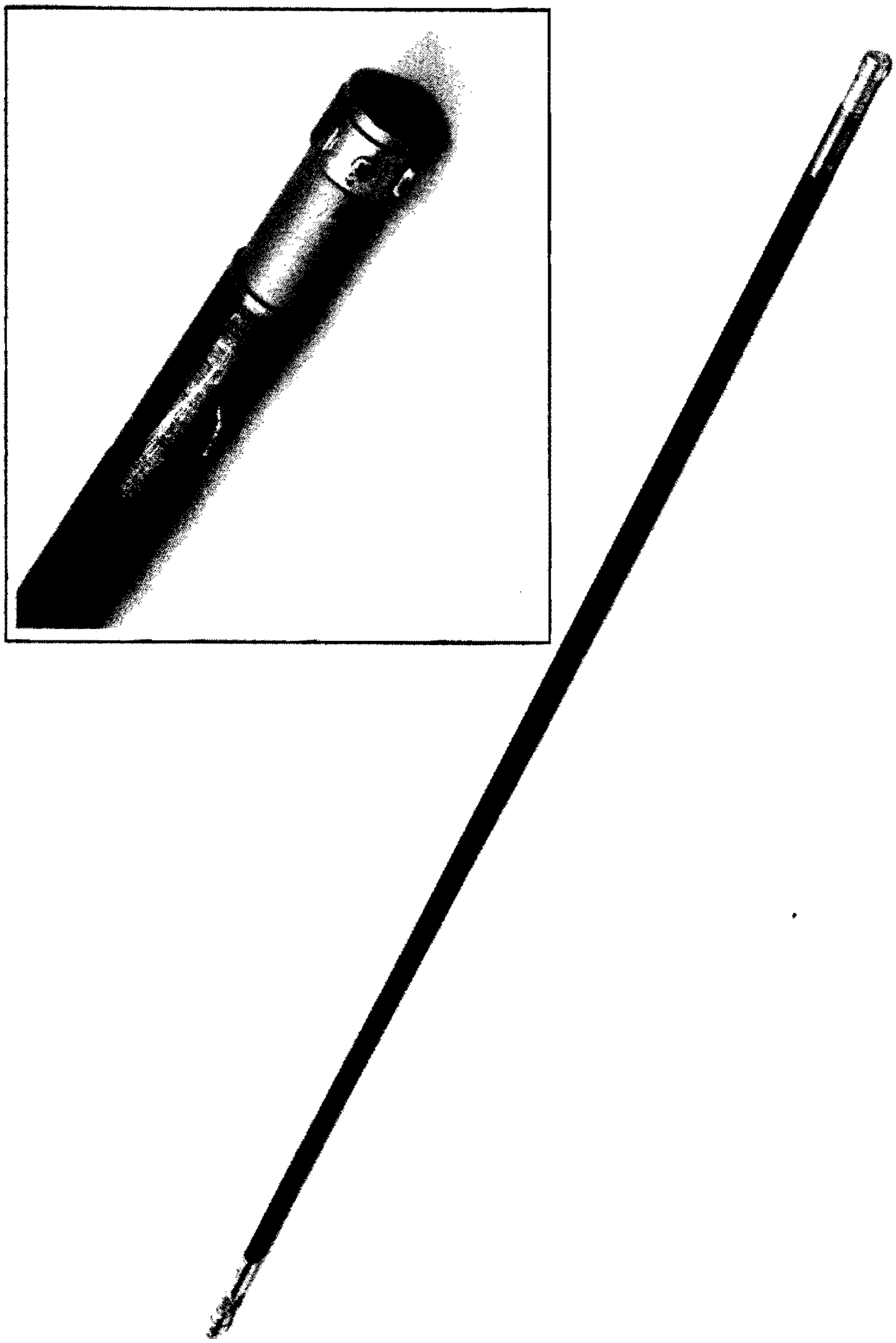


Figure 6. 20mm Bore Gauge

SECTION IV

M 39 TESTS

A. Firing Schedule Selection

Pertinent data on chrome-plated M39 barrels firing ball propellant ammunition were reviewed. Yaw failure at 2617 rounds was reported in Reference 2. The schedule employed in Reference 2 consisted of three 100-round bursts and one 75-round burst, with 15-second cooling intervals between bursts. Data from Reference 2 are plotted in Figure 7 for later comparison with data from the present study.

CAL data on barrel temperatures were consulted to guide burst-length selection. These data showed that a 250-round continuous burst could be fired without danger of gross plastic deformation. It was seen also that cooling after a burst was rapid at the breech end due to heat loss into the rather massive receiver section. This rapid cooling argued in favor of a continuous long burst rather than an interrupted schedule to maximize breech end temperatures and thus accelerate erosion. An interrupted schedule in the M39 tends to maximize other temperatures relative to the breech end.

It was clear from the literature that eroded M39 barrels generally failed by excessive yaw, i.e., 20 percent of the rounds of a burst exhibited yaw of 15 degrees or more.

A trial run 250-round burst of standard rounds in M39 barrel No. 1 indicated that the high erosion rate required for a study of the present scope was obtained. However, variations in hardness among barrels from the same box complicated initial testing, as discussed below.

Barrel No. 2 was instrumented and fired in a 250-round burst. Yaw failure was observed in the first 150 rounds, and keyholing persisted in single shots fired after cooling. Velocity dropped ~160 feet/second as determined by cold shots, and bore diameter increase was greater than 45 mils near the breech end. In summary, barrel No. 2 eroded to failure in less than one 250-round burst.

Hardness measurements indicated that barrel No. 2 was very soft (R_C 28). Barrel No. 1 and No. 3, from the same box, were found to measure R_C 34 and R_C 37, respectively. Since the temperatures reached during firing were under 900°F, which is too low to cause tempering (softening), it was speculated that low as-received hardness was part of the cause of the very rapid failure of barrel No. 2. However, it was also considered that 250 rounds might be too great a burst length; a 150-round burst length was decided upon for trial in barrel No. 3.

Results after three 150-round bursts indicated that erosion was proceeding very slowly in barrel No. 3. Since this barrel had a hardness of R_C 37, the evidence pointed to hardness as a predominant factor. It was decided that a burst length of 250 rounds (as originally chosen) should be appropriate for

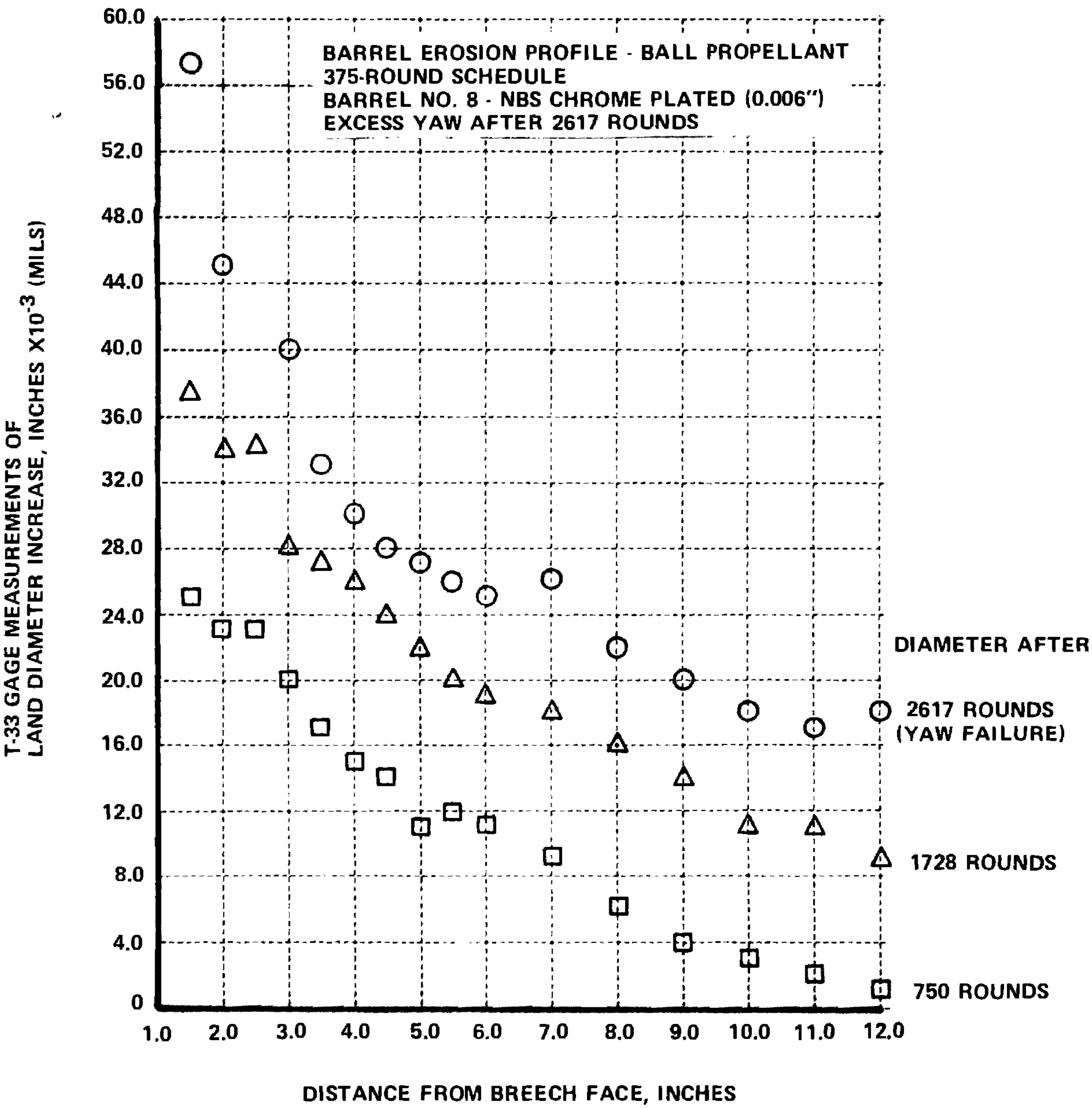


Figure 7. M39 Erosion Data From Reference 1

barrels in the R_c 37 hardness region, and additional barrels measuring R_c 35-37 were selected for further testing.

B. M39 Erosion Data

Three barrels in the R_c 35-37 hardness range were tested to yaw failure, two with standard ammunition and one with ablative. The results, summarized in Table VI, indicated that erosion failure by yaw took place with standard ammunition in less than 250 rounds when 250-round bursts were fired. The behavior of the two barrels was almost identical, with yaw failure occurring at 230* and 240 rounds, respectively. Inspection of the barrels revealed land stripping and severe internal deformation in the first 6 inches of the bore. Land diameters at the 1.5-inch station (B) are given in Table VI, but the observed deformation is so severe as to make measurements variable in the deformed region.

In the barrel firing ablative ammunition (barrel No. 8), the first 250-round burst was fired without stoppage, and the bore condition was found to be extremely good. No land wear was detected, velocity decrement appeared negligible, and there was no evidence of yaw.

In the next three attempts to fire 250-round bursts of ablative ammunition in barrel No. 8, stoppages occurred at 80, 170, and 162 rounds, as shown in Table VI. These gun failures appeared to be unrelated to the performance of the ammunition itself; such failures have often been experienced with standard ammunition in the past. Erosion appeared to progress very little in these firings, although there was some velocity decrement.

Following the above gun failures, successful bursts of 248, 250, and 250 ablative rounds were fired through barrel No. 8. Yaw failure was observed early in the final burst at round 1211.

If the most conservative viewpoint were to be taken with respect to life increase, the abortive bursts of 80, 170, and 162 rounds would be ignored (considered to have caused no erosion), and yaw failure would be pegged at a total of 799 rounds. Since the barrels firing standard ammunition failed at 230 and 240 rounds, respectively, this life increase was more than 300 percent. Considering, however, that some damage was caused by the abortive bursts (which totaled 412 rounds), the actual yaw life increase may have been 400 percent or more. (Velocity failure was not reached in any barrel tested.)

M39 bore profile data are plotted in Figures 8-10. Figure 8, showing complete bore profiles after 250 rounds, indicates clearly the superiority of the ablative ammunition. Figure 9, a plot of the same data on expanded scales, shows the bore erosion at a point 1 inch from the breech end to have been six times more severe for standard ammunition than for ablative.

* The stated failure round is the eighth round to yaw greater than 15 degrees in any series of 40; i.e., when 20 percent of any 40-round series yaws greater than 15 degrees.

TABLE VI. M39 EROSION TEST DATA

AMMO. TYPE	BARREL NO.	TEST NO.	HARDNESS R_c	FIRING		ΔVELOCITY[3] (ft/sec)	YAW (> 15°)		EROSION (mils[6])	STOPPAGE CAUSE
				LOADED/FIRED	TOTAL		FAILURE[4]	COLD[5]		
STD.[1]	4	12	37	250/250	250	15–20	RD. 230	1 OF 5	3–17	
STD.[1]	6	21	35	250/248	248	20–25	RD. 240	NONE	21	RD. 249 JAMMED
ABLATIVE[2]	8	14	37	250/250	250	0–5	NO	NONE	0	
ABLATIVE[2]	8	15	37	250/80	330	MISSED	NO	NONE	0	FIRING PIN
ABLATIVE[2]	8	16	37	250/170	500	30–50	NO	NONE	0	FIRING PIN
ABLATIVE[2]	8	17	37	250/162	662	MISSED	NO	NONE	0	EJECTOR BROKEN
ABLATIVE[2]	8	18	37	250/248	910	20–50	NO	NONE	6	RD. 249 JAMMED
ABLATIVE[2]	8	19	37	250/250	1160	80-100	NO	NONE	8	
ABLATIVE[2]	8	20	37	250/250	1410	60–70	RD. 1211	3 OF 10	10	

NOTES:

1. LOT KOP-L-153-5, WC 870 BALL PROPELLANT.
2. ABLATIVE AMMUNITION CONTAINS 575 GRAINS COMPACTED WC 870 PROPELLANT, AND 77 GRAINS THICKENED 100,000 CSTKS VISCOSITY SILICONE.
3. DECREMENT IN VELOCITY COMPARED TO AS-RECEIVED BARREL, DETERMINED FROM 5 SHOTS IN COLD BARREL.
4. ROUND IN BURST AT WHICH EIGHT YAWS >15° ARE ACCUMULATED IN ANY 40 ROUND SERIES.
5. YAWS> 15° OBSERVED IN FIRING FIVE TO TEN ROUNDS AFTER COOLING.
6. LAND DIAMETER INCREASE AT STATION B, 1.5" FROM BREECH END.

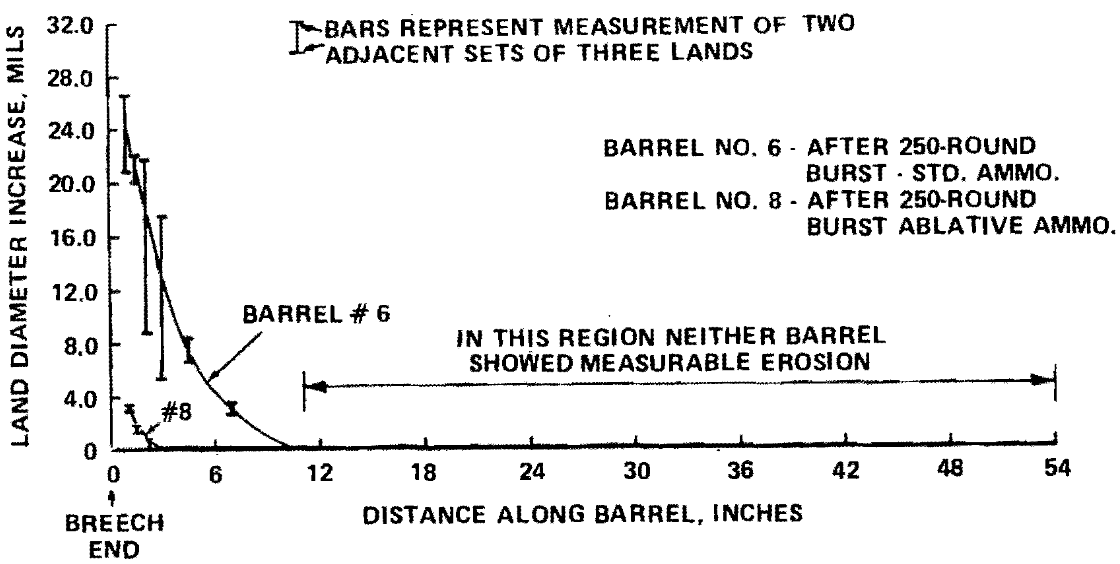


Figure 8. M39 Bore Erosion Profiles – Ablative Versus Standard Ammunition, 250 Rounds Each

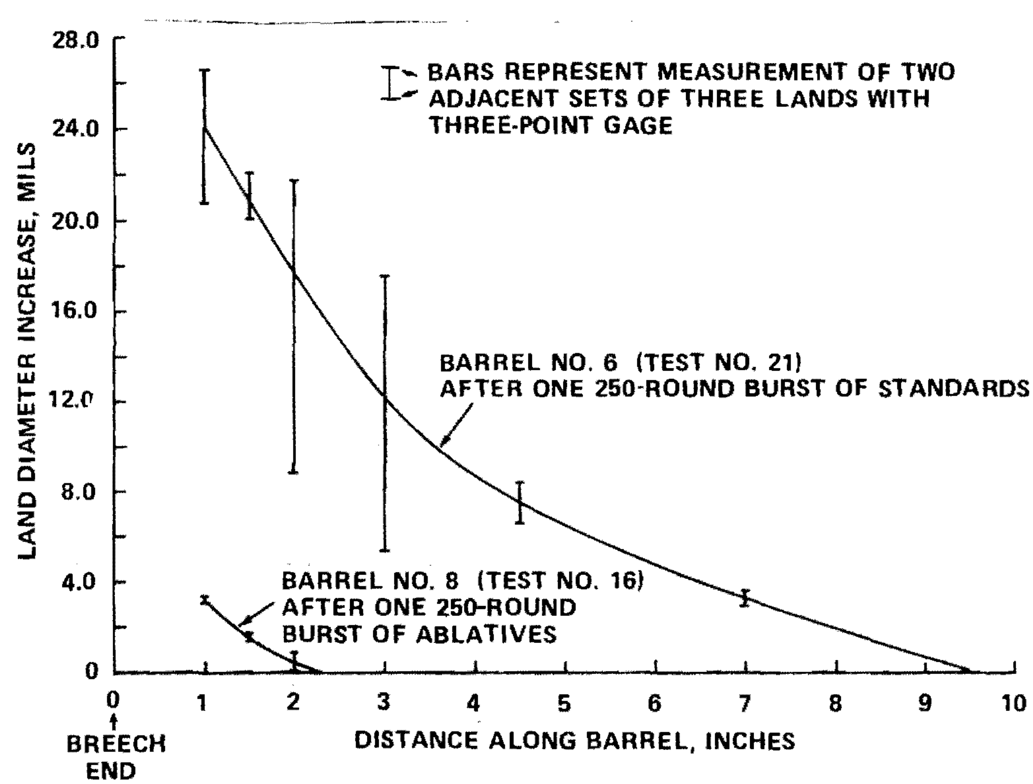


Figure 9. M39 Breech End Bore Erosion Profiles – Ablative Versus Standard Ammunition, 250 Rounds Each

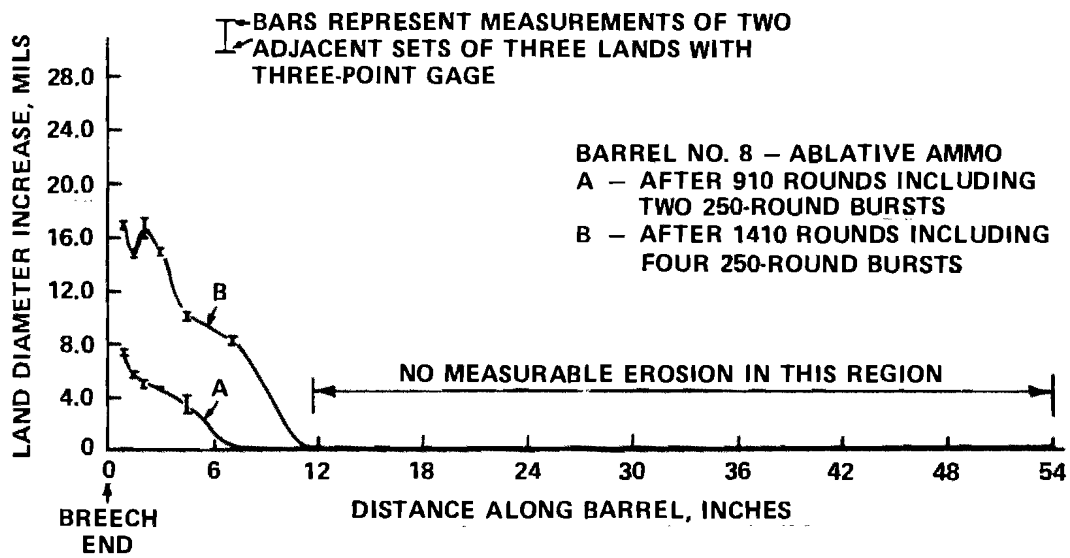


Figure 10. M39 Bore Erosion Profile – Ablative Ammunition

Ablative ammunition performance is further depicted in Figure 10. After 910 total rounds, the land diameter increase at the 1-inch station was less than 8 mils, and after 1410 rounds the increase was approximately 16 mils. While yaw failure was observed early in the final 250-round burst (at 1211 rounds), bore erosion was not extremely severe.

Close examination of the groove diameter data taken in each M39 test barrel indicated that the data were not entirely meaningful. In the forward half of the barrels there were no significant changes from the new condition. In the breech end, severe land flattening interfered with proper seating of the gage pins in the grooves. Also, in the barrel firing silicone-modified ammunition, heavy coppering deposits which formed in the breech end prevented proper gaging of the grooves. The gage pins were later modified to seat more readily into the rifling grooves.

Coppering and other features of the eroded bores were subjected to study. The results of these studies, which include chemical analysis, electron microprobe examination, and metallographic examination, are discussed in Appendix I. It appeared probable that even larger barrel life improvement could be achieved if coppering could be reduced in future studies.

C. Temperature Instrumentation

Two types of temperature data were recorded during the sustained firing of the M39. Barrels were fitted with five in-wall thermocouples at the locations shown in Figure 11. The depth of each thermocouple well was made two-thirds of the wall thickness. It had been previously calculated that the temperature at the two-thirds point would be a good approximation of the average temperature both during the course of a burst when heating was extremely rapid and the temperature gradients were large and during barrel cooling.

Design details of the in-wall thermocouples, which proved reliable in previous work, are shown in Figure 12. The simpler Type 1 assemblies were threaded directly into the barrel at Stations C through E, while the spring-loaded Type 2 units were mounted in the receiver and extended into the barrel wall at Stations A and B. Thermocouple readout was accomplished with a multichannel light-beam oscillograph operating at a chart speed of 2 inches per second.

Drum temperatures were obtained by the use of 25 drum thermocouples, the locations of which are depicted in Figure 13(A). The contactor, shown in Figure 13(B), was remotely controlled to make momentary contact with any set of five thermocouples presented when the gun was stopped. Drum temperature readout was accomplished with a Leeds and Northrup AZAR potentiometric recorder with manual switching such that each thermocouple was recorded approximately four times per minute.

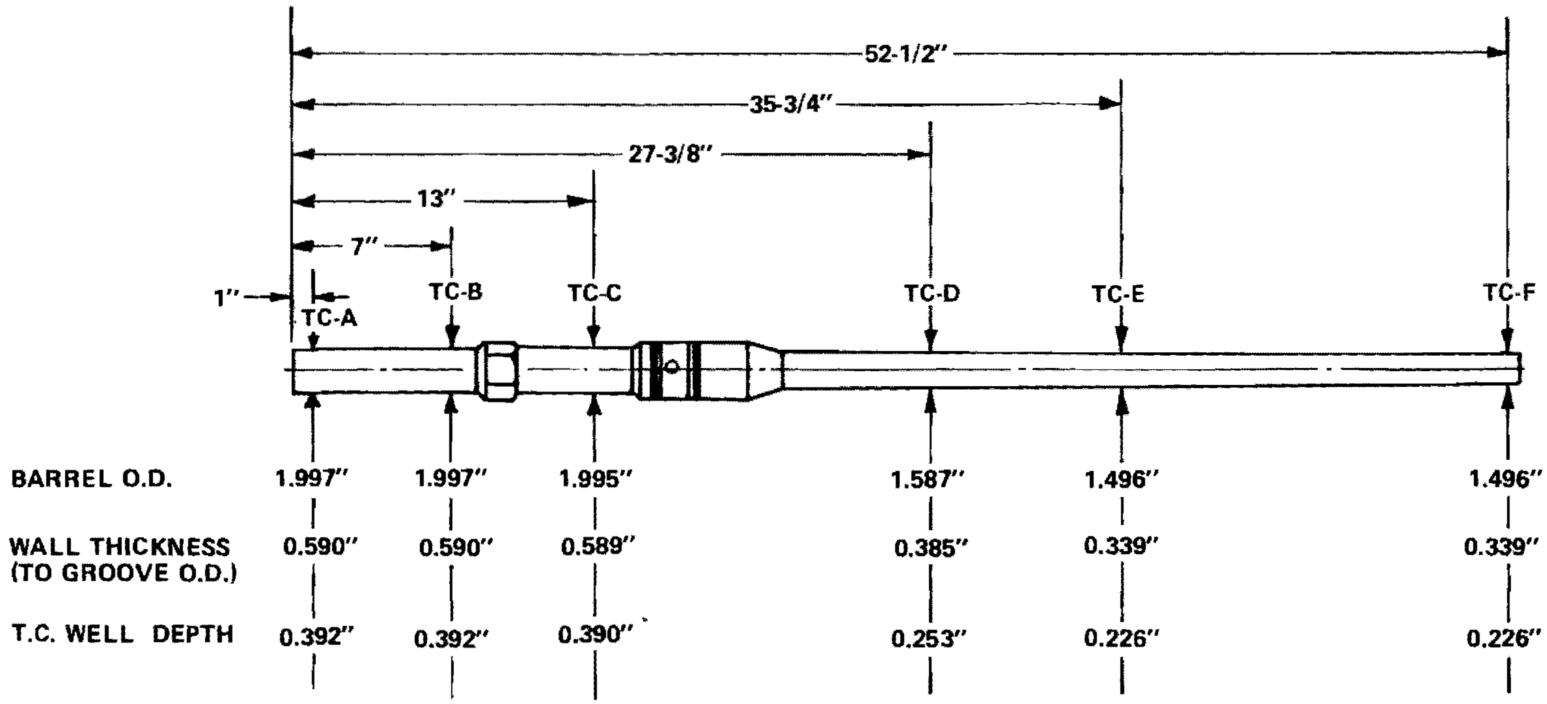
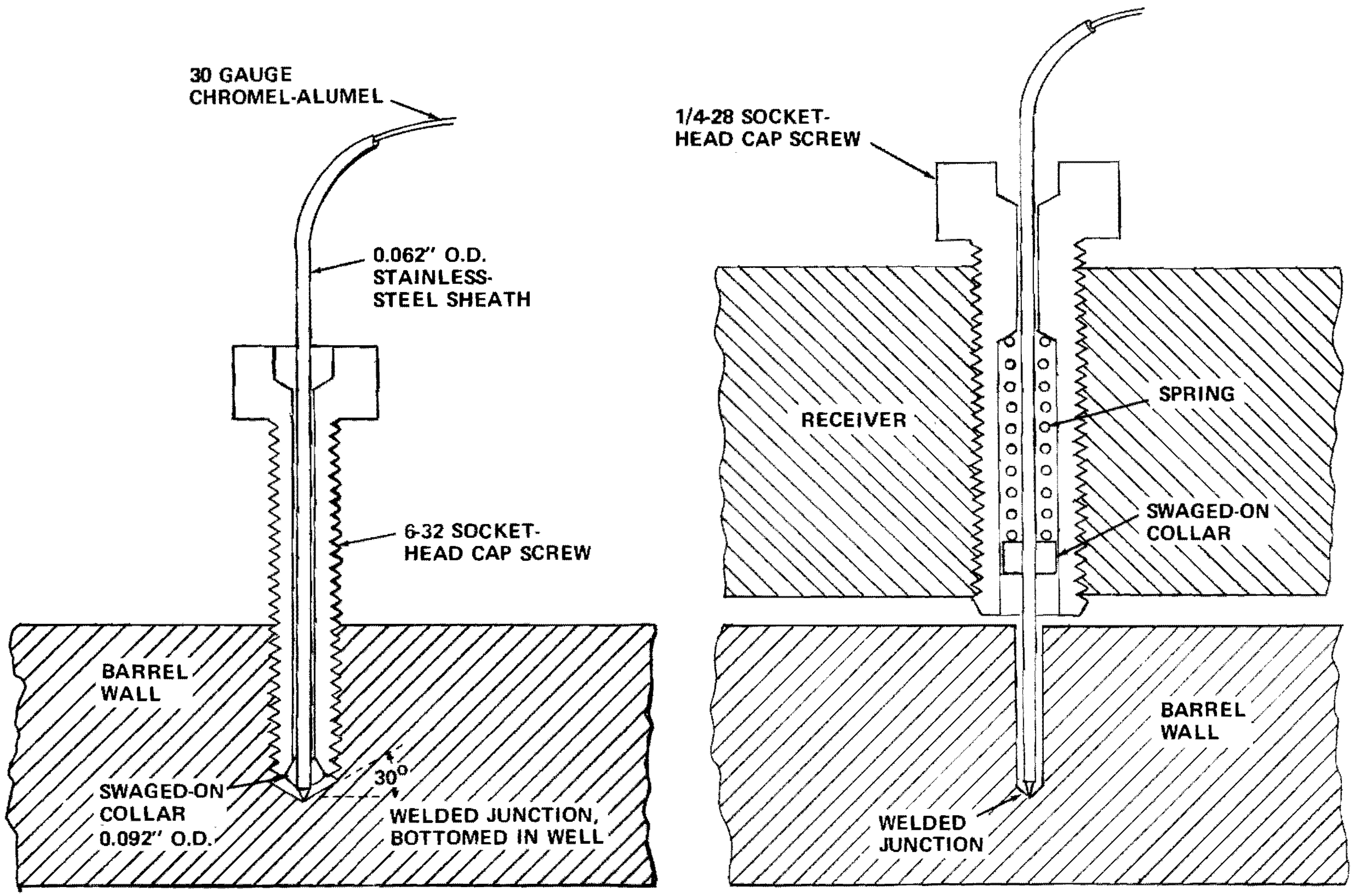


Figure 11. In-Wall Thermocouple Stations in the M39 Barrel



TYPE 1

TYPE 2

Figure 12. In-Wall Thermocouple Detail

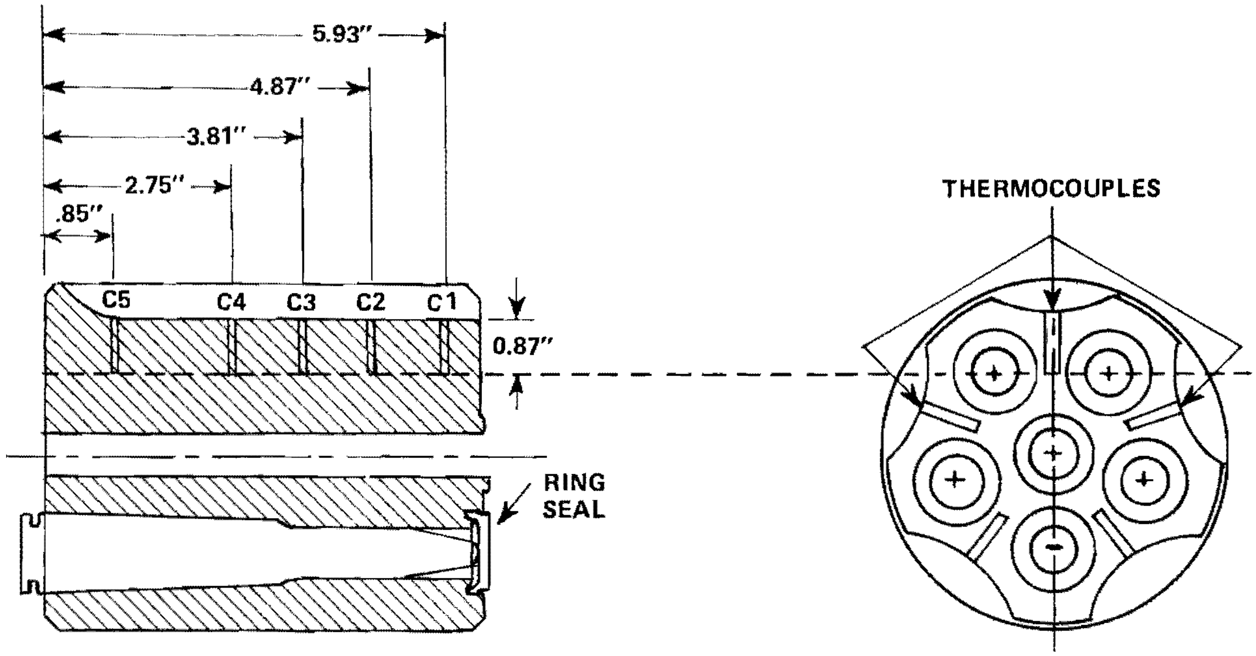


Figure 13(A). In-Wall Thermocouple Locations in the M39 Drum

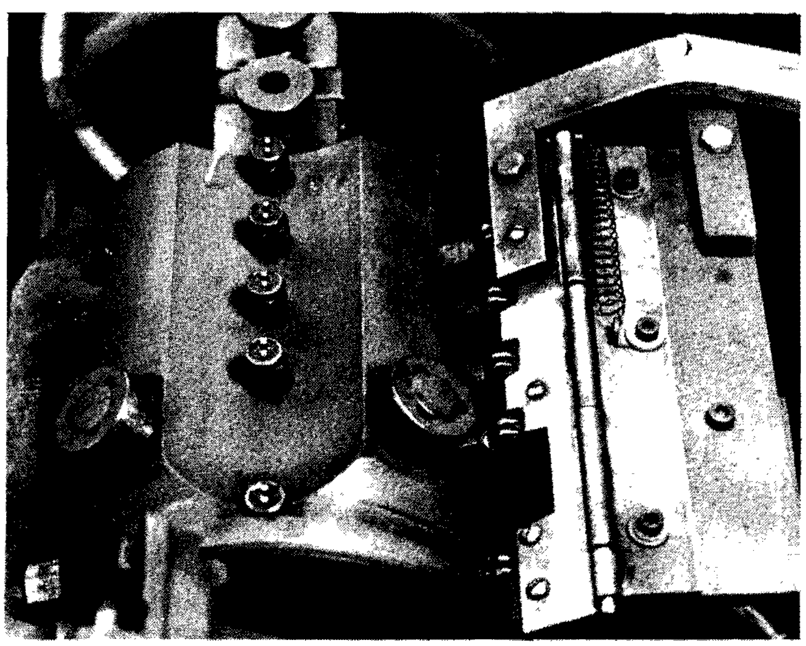


Figure 13(B). M39 Drum Showing Thermocouples and Contactor

D. Temperature Data

In the M39 cannon, the first portion of projectile travel is in the revolving drum. The silicone gel was found to be effective in reducing heat input in the drum and in the first several inches of the barrel. Drum heating data for standard and ablative ammunition are plotted in Figures 14 and 15. No data were taken from drum thermocouple C5 since this position has little significance to cook-off. An analysis of the extended cook-off - safe firing capability that would be obtained in firing ablative ammunition is given in Section VI of this report.

Barrel heating data are plotted in Figures 16-19. Thermocouple failures due to vibration prevented data acquisition from barrel Stations B and F, and data scatter was greater than normal at Station A. However, moderate temperature reduction in the breech end of the barrel was established.

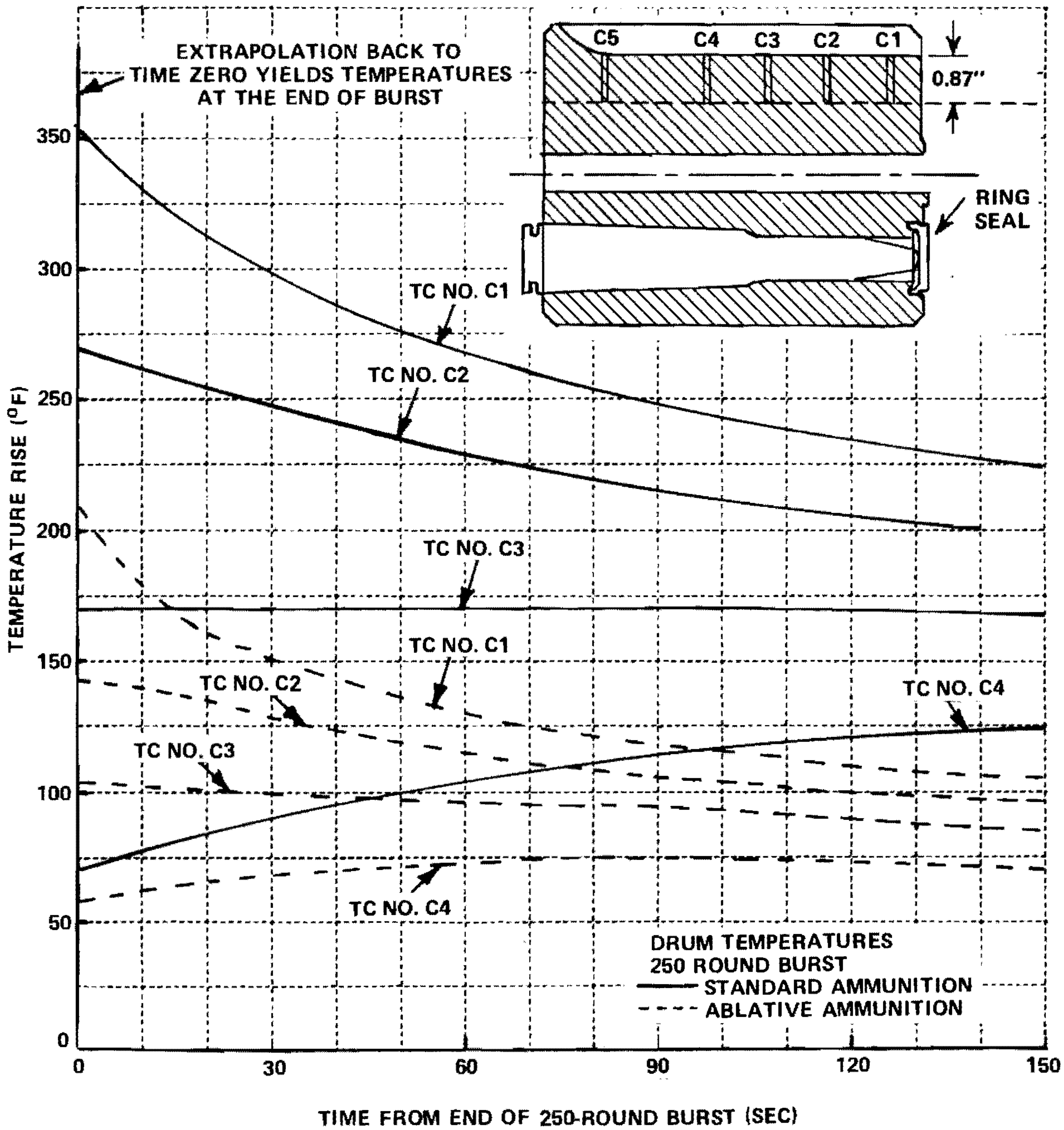


Figure 14. M39 Drum Temperatures After 250-Round Burst

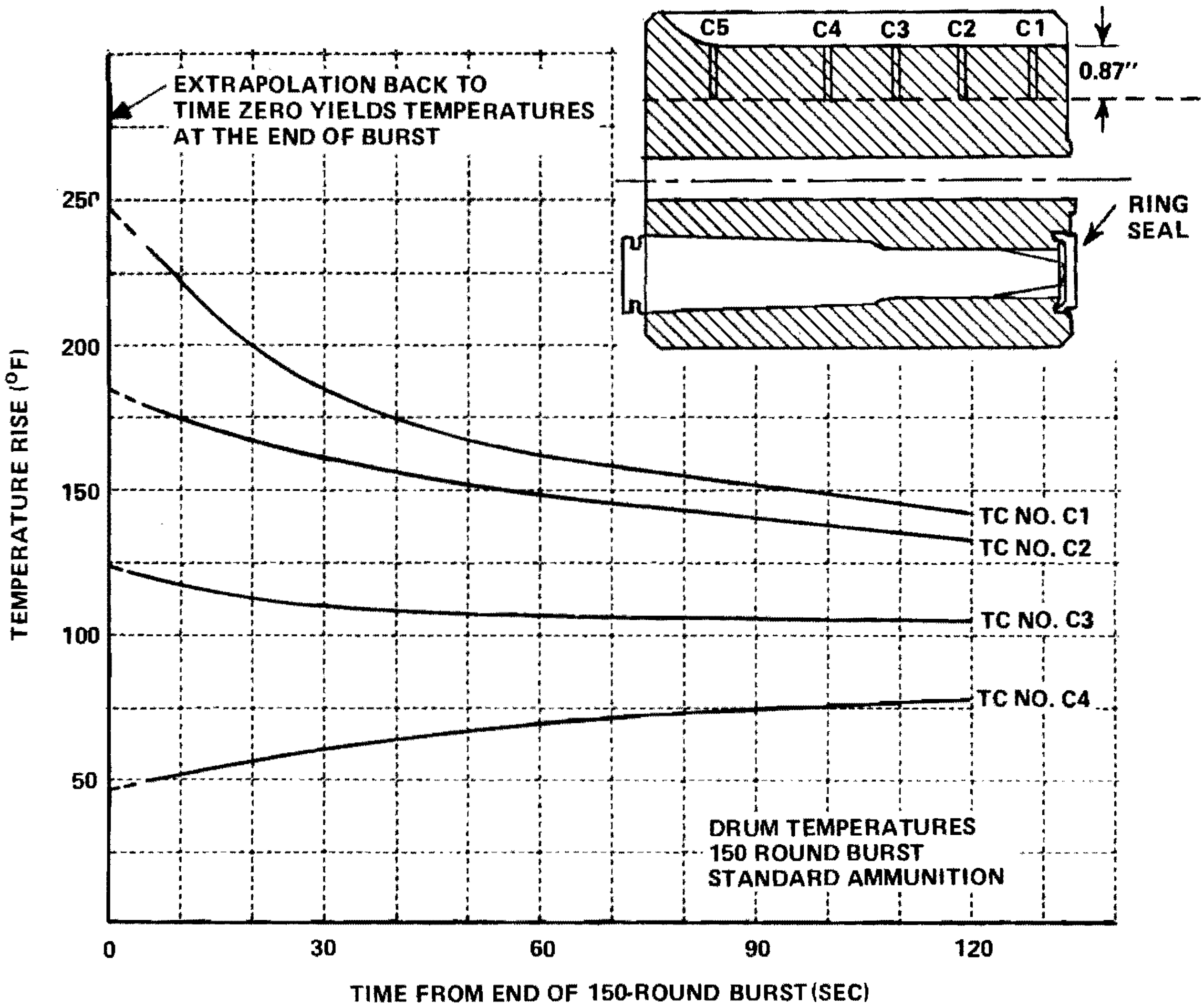


Figure 15. M39 Drum Temperatures After 150-Round Burst of Standard Ammunition

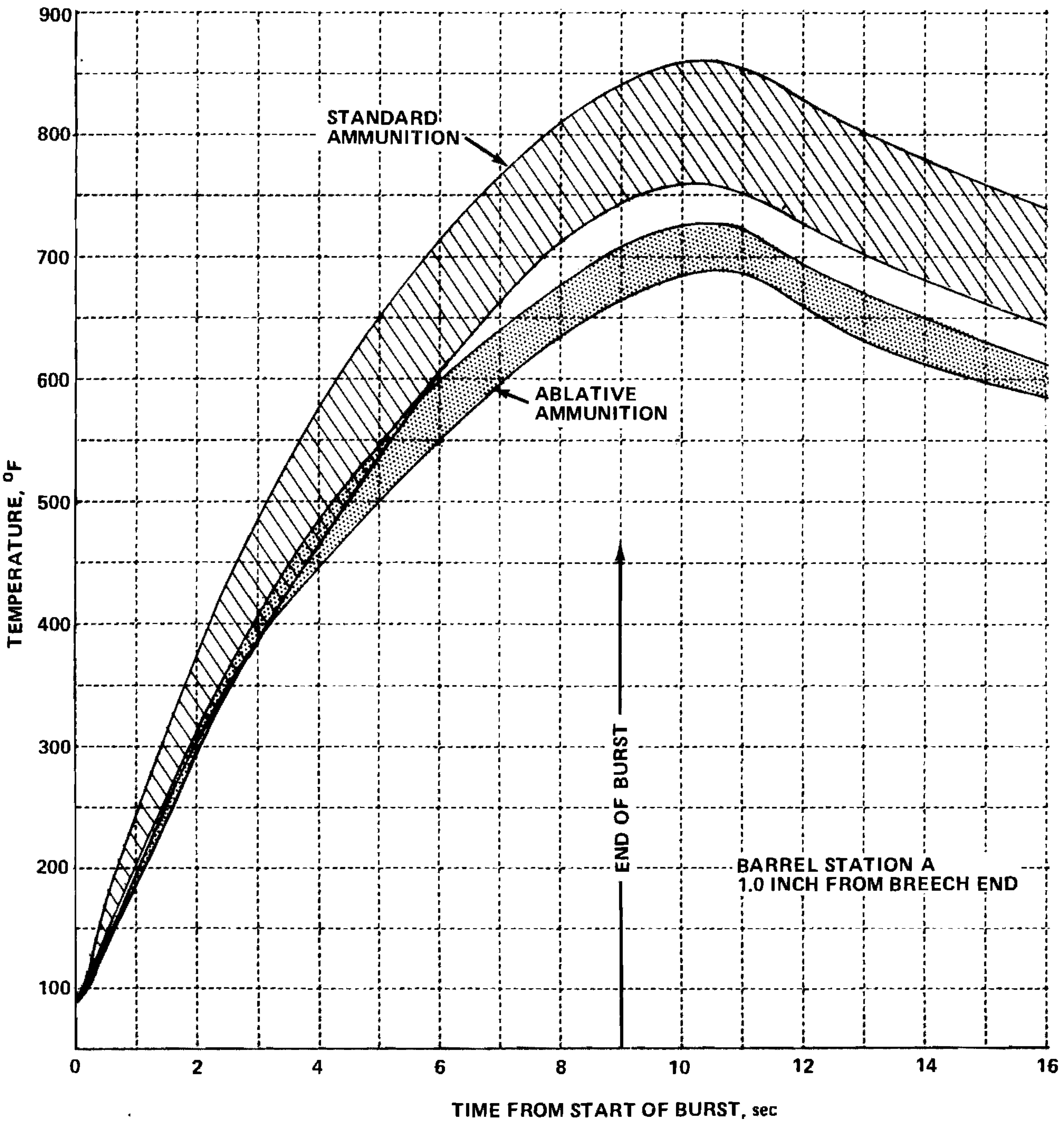


Figure 16. M39 Barrel Temperatures in 250-Round Burst

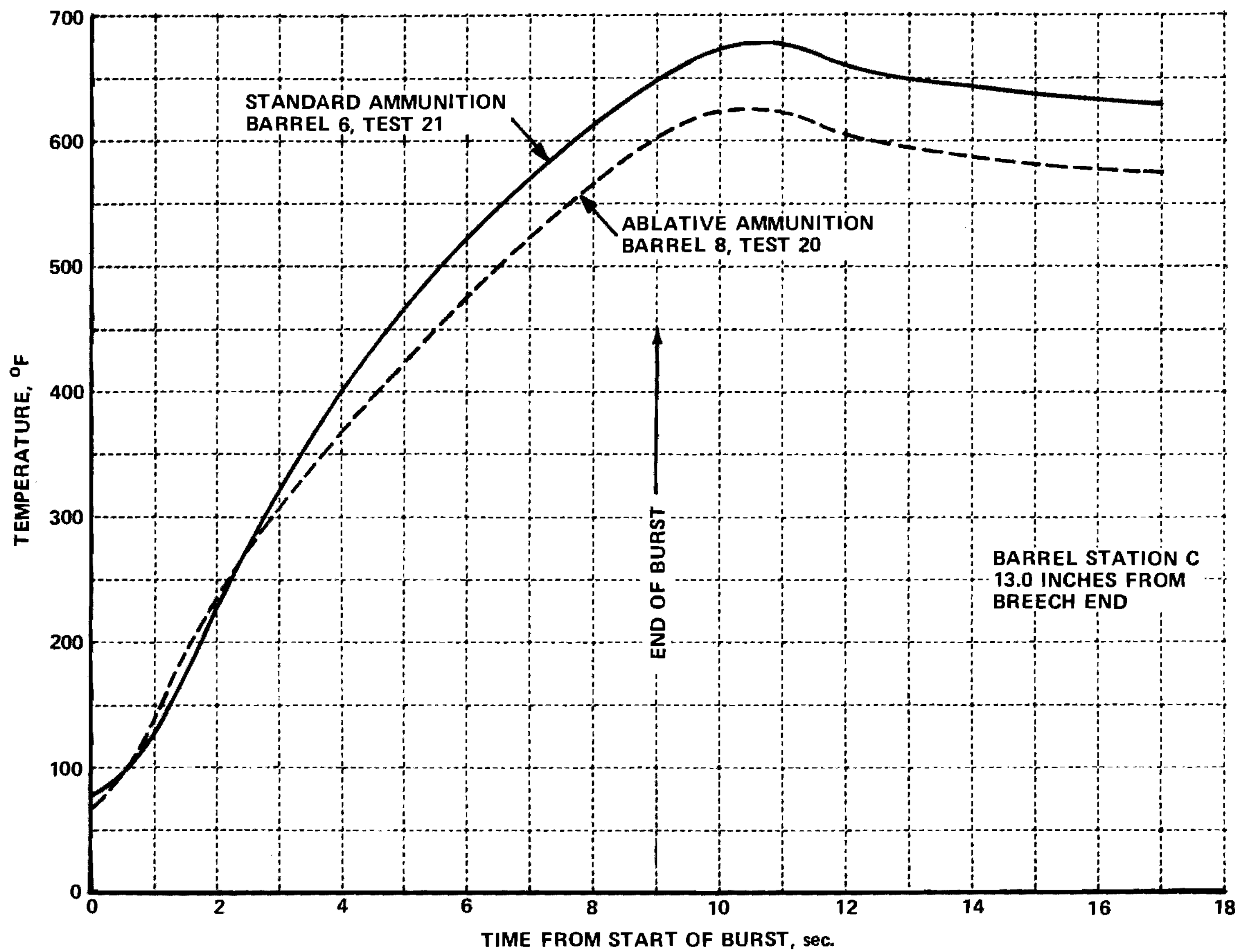


Figure 17. M39 Barrel Temperatures in 250-Round Burst

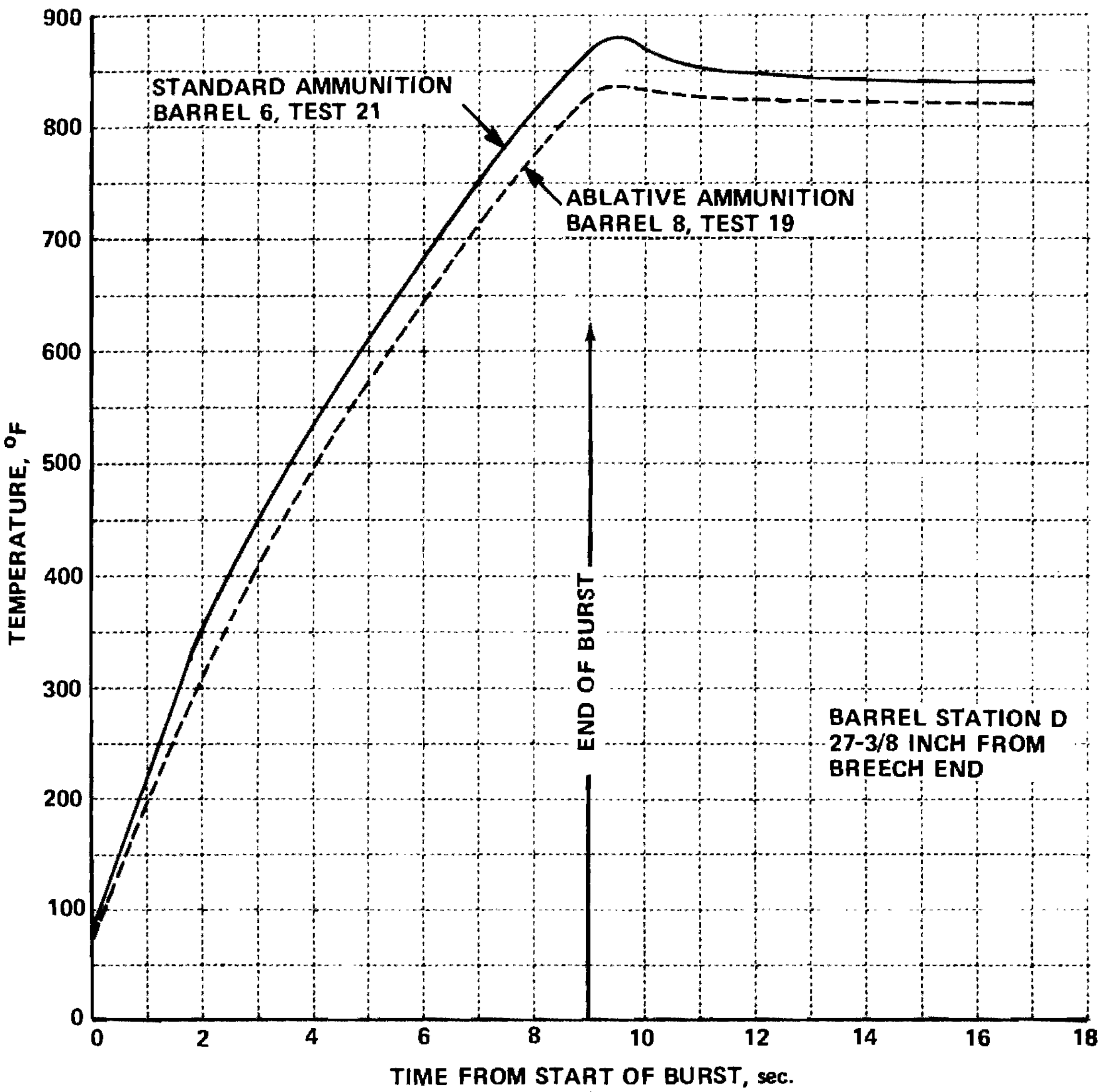


Figure 18. M39 Barrel Temperatures in 250-Round Burst

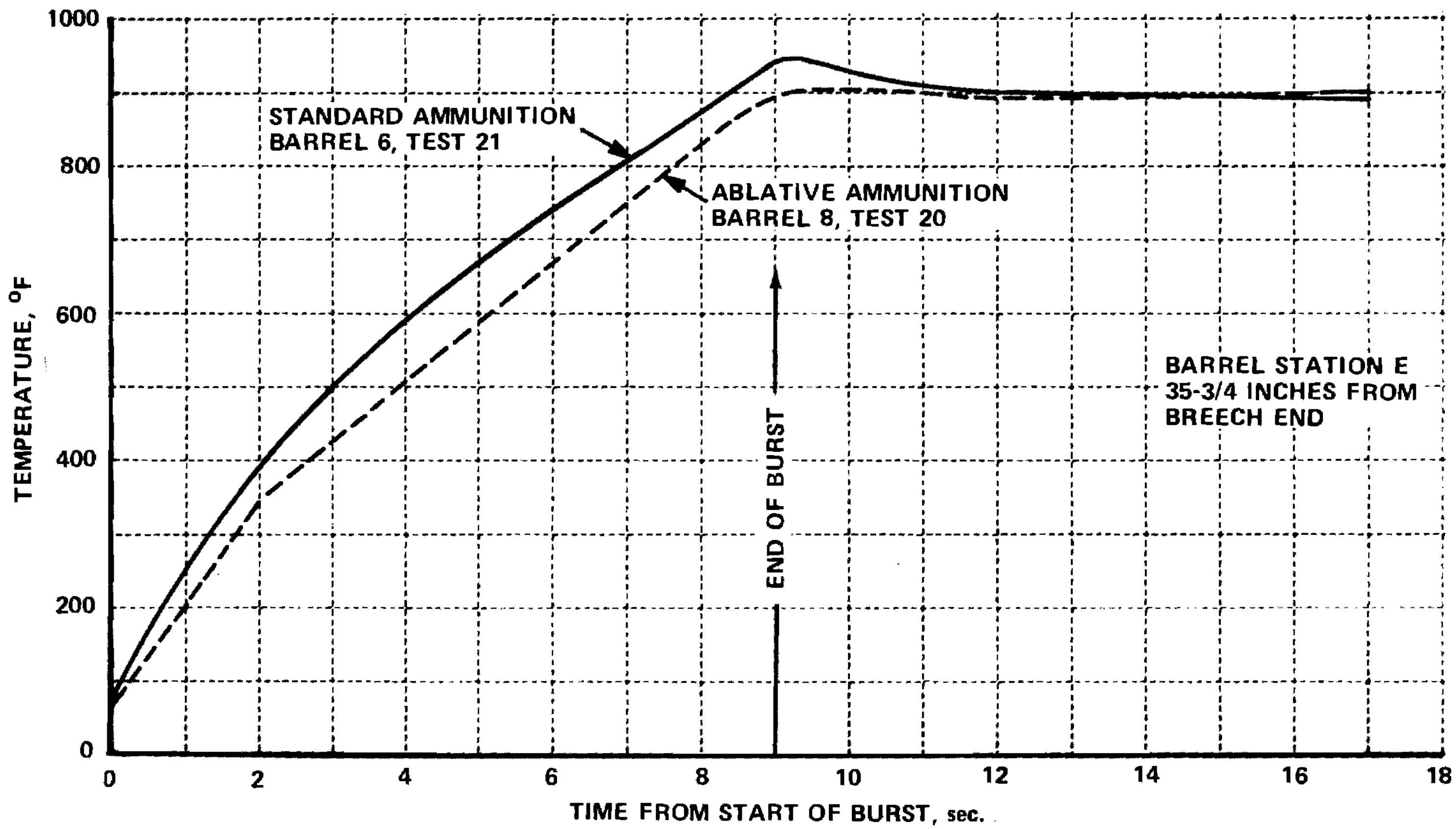


Figure 19. M39 Barrel Temperatures in 250-Round Burst

SECTION V
M61 TESTS

A. Firing Schedule Selection

The purpose of this program phase was to study ablative ammunition as a means of reducing M61 gun barrel heating and erosion. Severe firing schedules were desired so that the sought-after effects would become apparent in relatively few rounds. Considerable literature review, consultation, and analysis led to the conclusion that a barrel temperature of ~1400°F was the maximum allowable value without danger of catastrophic failure. A schedule consisting of 200 rounds per barrel per burst was required to generate this temperature. A firing rate of at least 4000 rounds per minute was required to generate a realistic temperature gradient at the bore surface.

It was decided that rounds would be fired from every other barrel, standard rounds from two barrels and ablative rounds from one or vice versa. This firing sequence was chosen to conserve ammunition, reduce gas generation in the underground gun range, and reduce the number of perforations in the moving witness while maintaining firing symmetry.

B. Gun and Installation

The M61 gun was installed in the CAL underground gun range as shown in Figure 20. The various items called out in this figure and others pertinent to the test setup are discussed below.

1. Gun System

The M61 gun system was driven by a T35-E1 drive unit consisting of a D. C. motor with a rated maximum electrical power input of 485 amperes at 28 volts; this input is capable of operating the gun at a firing rate in excess of 4000 rounds per minute. The electrical power for the motor was supplied by one 24-volt and one 12-volt battery connected electrically in a series circuit. This supplied an initial voltage of 36 volts which dropped to 25 volts during the run. This hook-up drew a current of 400 amperes and turned the gun at an average firing rate of 4350 rounds per minute.

The gun incorporated a feeder for use with M14 linked 20mm ammunition.

Three of the six barrels were fired during a burst as discussed in the previous section. This was achieved by removing the firing pins from the bolts of the nonfiring barrels. Rounds were cycled through the gun along with spent cases from the firing barrels. Every other barrel was hot and grew approximately 3/8 inch in length while the cold barrels remained the same length during a test. The barrel clamp was attached to the hot barrels for the first series of tests, which permitted the clamp to slide over the cold barrels. This clamping configuration caused the barrels to whip during a test, which resulted in large scatter at the target. It was postulated that the reason for this was related to unequal growth of the barrels firing standard

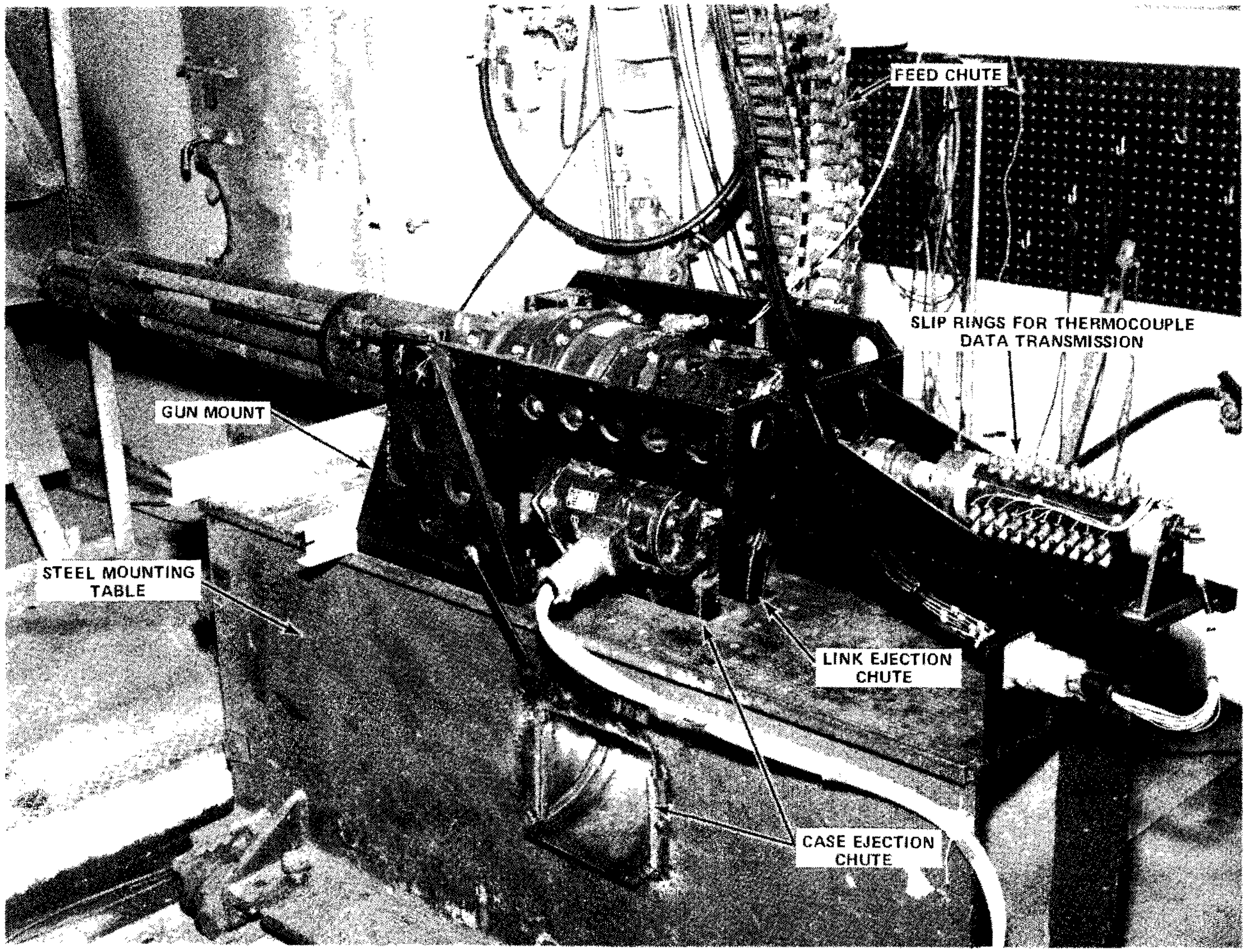


Figure 20. M61 Test Set-up

and ablative ammunition and movement of the barrel clamp on the cold barrels to a point where the clamp was loose on the cold barrels. To alleviate this problem, the barrel clamp was attached to the cold barrels, and the ends of the hot barrels were machined to permit easy sliding in the clamp.

2. <u>Gun Mount</u>

The M61 gun and cradle were attached to a steel mounting table with bolts and dowel pins. The table inclination was adjusted with jack screws to provide proper gun barrel alignment with respect to the gun range.

3. <u>Ejection Chutes</u>

Two ejection chutes were fabricated from sheet metal; one carried spent cases and the other separated ammunition links from the gun. These chutes were attached to their respective ejector fittings on the gun. The cases were routed to the floor area on the left side of the gun and the links to the floor on the right side.

4. <u>Feed Box</u>

A feed box capable of holding over 1200 rounds was designed and fabricated by CAL. The box consists of a base and two plywood sides with a sliding track on top. The inner surface of the sides is covered with sheet aluminum, and the top tracks are covered with sheet steel to provide smooth sliding surfaces. The box is designed to hold the ammunition in loops as shown in Figure 21. Each loop contains a maximum of 60 rounds and is supported at each end by one round which rests on the sliding track. As ammunition is consumed, the supporting rounds are pulled along the track. A bell mouth is mounted at one end of the track so that supporting rounds and the loops of rounds enter the feed chute with minimum resistance and link stress.

5. <u>Feed Chute</u>

Space and other considerations made it advisable to locate the feed box in the room above the gun range and feed the ammunition through a 12-foot-long feed chute. This arrangement produces a siphon effect which substantially reduces the force required by the gun to initiate and sustain the flow of ammunition. Feed chute routing is shown in Figures 20 and 21.

6. <u>Temperature Data Transmission</u>

Temperature instrumentation is described in Section D below. The most important element of the system was the slip-ring device shown at the right in Figure 20.

7. <u>Water System</u>

The M61 is in danger of cook-off after a burst of 600 standard rounds has been fired or when a single barrel has fired a burst of at least 100 rounds.

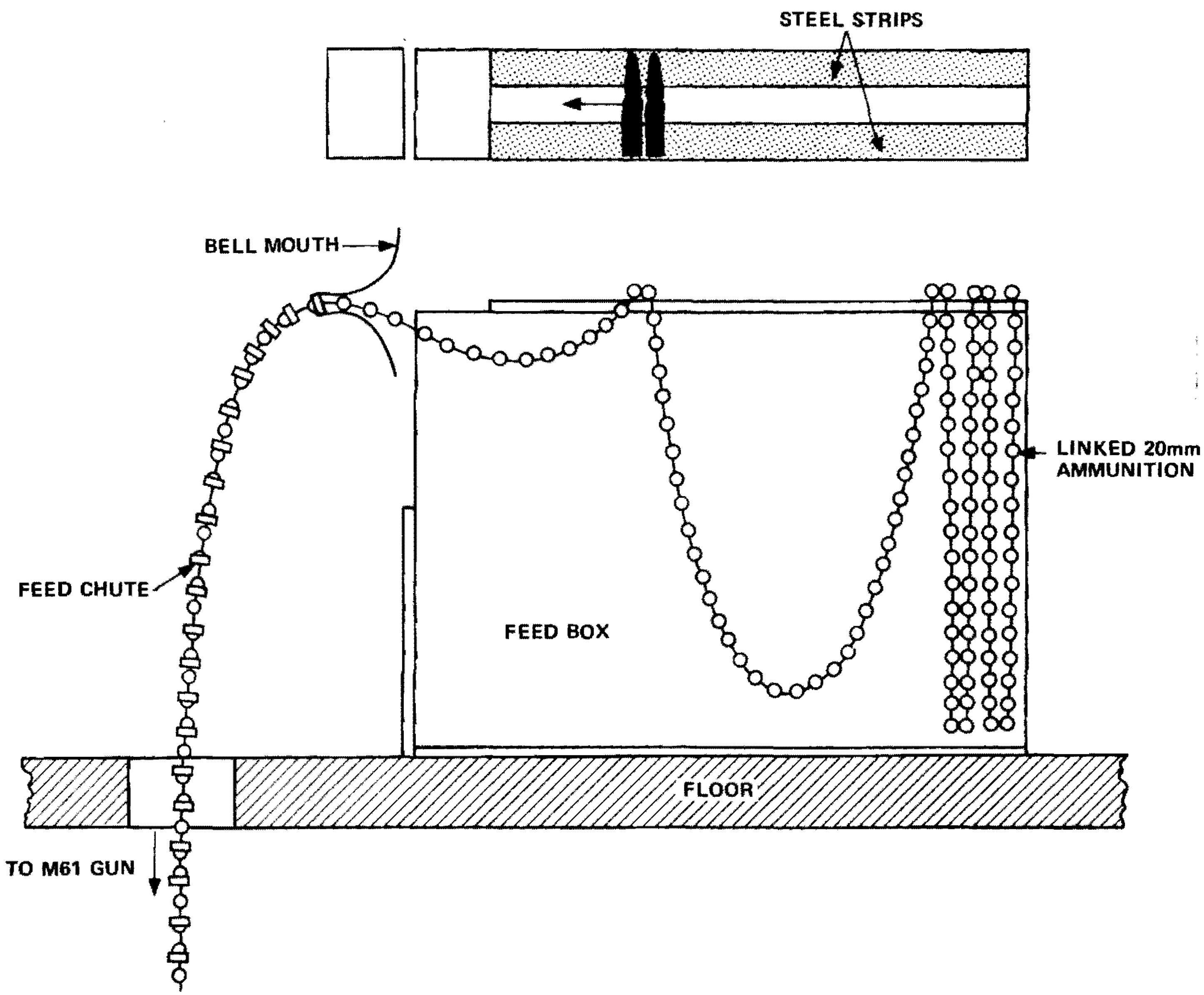


Figure 21. Schematic Diagram of M61 Ammunition Feed System

The firing schedule was chosen to be 200 rounds per barrel, and cook-off would occur if the gun should become jammed toward the end of the burst. A manually actuated water deluge system was installed with four separate nozzles aimed at the breech end of the barrels.

C. Erosion Data

Erosion testing was somewhat hampered by stoppages, barrel bending, and a cook-off which damaged the gun. The stoppages were caused by link and feeder failures. Barrel bending was believed to be due to sudden stoppages with the barrels hot, binding in the barrel clamps, and warpage or stress-relief due to the extremely high temperature reached.

Data are summarized in Table VII. The first set of three active (firing) barrels was put aside after ~1176 rounds per barrel, which included four 200-round bursts and three shorter bursts with stoppages or jams. Barrel bending was severe, and dispersion at ~1000 inches was too large for the revolving yaw target. Yaw failure had not occurred, but yaws of less than 15 degrees were observed in standard rounds fired from barrel No. 3. Erosion near the origin of rifling (at the 5.5-inch station) was greater than 28 mils in the two standard barrels but was only 7.2 mils in the barrel firing ablative ammunition.

In the second set of barrels tested, a jam took place after ~176 rounds, and bending was severe in barrels No. 2 and No. 5, which were put aside after one additional 200-round burst. The bore of the barrel firing silicone-modified ammunition gaged smaller than as-received due to coppering. It was noted that coppering was quite severe in each barrel firing ablative ammunition.

Barrel No. 9 (firing standard ammunition) was in good condition after 376 rounds and was retained in the third set of three active test barrels. Yaw failure took place in barrel No. 9 at 925 rounds, and the land diameter increase at the 5.5-inch station was 29.6 mils. Four of six cold shots keyholed at 1000 inches, and the velocity decrement was 100 feet/second relative to the as-received value.

Barrel No. 10 of the same set also fired standard ammunition. Yaw failure took place at round 417, i.e., at the seventeenth round of the third 200-round burst. Inspection of the barrel after 600 rounds revealed severe bending and bulging near the muzzle; this deformation may have contributed to premature yaw failure. The increase in land diameter at the 5.5-inch station was 25.2 mils.

Barrel No. 11 fired 600 silicone-modified rounds in parallel tests with barrel No. 10. Land diameter increase at the 5.5-inch station was only 3.3 mils. No hot or cold yaws were observed, but coppering was heavy; it was decided to section and examine the tube rather than to continue firing. Barrel No. 10 was also sectioned to provide direct comparison. The results of the metallographic, electron microprobe, and analytical studies conducted are presented in Appendix I.

TABLE VII. M61 EROSION DATA

AMMO. TYPE	BARREL NO.	BARREL SET	TEST NOS.	HARD. R_C	TOTAL ROUNDS PER BARREL	ΔVELOCITY[3] (ft/sec)	YAW AT 1000 INCHES FAIL.[4]	YAW AT 1000 INCHES COLD[5]	EROSION MILS[6]
STANDARD[1]	1		101-107	32	1176	155	NO	NO	+29.9
STANDARD	3	1	101-107	35	1176	134	NO	<15°	+28.7
ABLATIVE[2]	8		101-107	32	1176	123	NO	NO	+ 7.2
STANDARD	5		108-109	33	376	32	NO	NO	+20.2
STANDARD	9	2	108-109	31	376	36	NO	NO	+23.2
ABLATIVE	2		108-109	33	376	22	NO	NO	– 5.0
STANDARD	9		108-112	31	976	100	925	5 OF 7	+29.6
STANDARD	10	3	110-112	35	600	147[7]	417	NONE	+25.2
ABLATIVE	11		110-112	35	600	102	NO	NONE	+ 3.3

NOTES:

1. LOT LCL-24-291, WC870 BALL PROPELLANT
2. ABLATIVE AMMUNITION CONTAINS 585 GR. COMPACTED WC 870 PROPELLANT, AND 77 GR. THICKENED 60,000 CSTKS VISCOSITY SILICONE.
3. DECREMENT IN VELOCITY COMPARED TO AS-RECEIVED, DETERMINED FROM 5 SHOTS IN COLD BARREL AFTER EACH BURST.
4. ROUND AT WHICH EIGHT YAWS >15° ARE ACCUMULATED IN ANY 40 ROUND SERIES.
5. YAWS >15° OBSERVED IN FIRING FIVE TO TEN ROUNDS AFTER COOLING.
6. LAND DIAMETER INCREASE AT STATION 5.5 INCHES FROM BREECH END.
7. BASED ON 2 SHOTS. BARREL FAILED AFTER SECOND COLD SHOT.

Land diameter profiles for barrels No. 10 and No. 11 are shown in Figure 22*. (Barrels No. 1, No. 3, and No. 8 fired more rounds but were too severely bent to permit gaging.) While Figure 22 represents only 600 rounds in each barrel, the data indicated that the silicone-modified ammunition produced less erosion near the origin of rifling. However, coppering on the lands was seen to be substantial with the modified ammunition, from a point about 8 inches from the breech end to one roughly 40 inches forward. A diameter increase is shown near the muzzle of barrel No. 11; barrel No. 10 was similarly eroded but was bent too severely to permit gaging.

Groove diameter data (Figure 23) showed heavy coppering in barrel No. 11 and some in barrel No. 10. Since the gage cannot distinguish between deposits and the swaging of lands into the grooves, some ambiguity is associated with the data of Figure 23.

Velocity performance data, as given in Table VII, indicate somewhat less overall velocity degradation in barrels firing silicone-modified ammunition than those firing standard ammunition, except in the case of barrel No. 9. Table VIII illustrates the velocity performance history of barrels No. 10 and No. 11, where it may be observed that, although slightly greater degradation was found for the ablative barrel in the first 400 rounds, increased degradation in the standard barrel through the next 200 rounds overcomes the early advantage of the standard ammunition.

TABLE VIII. M61 VELOCITY PERFORMANCE

	Barrel History			
Barrel No.	New	200 Rounds	400 Rounds	600 Rounds
10 (Std.)	3365	3325	3320	3220[a]
11 (Abl.)	3365	3315	3300	3260

[a] Barrel ruptured near muzzle after two cold shots. All other data points represent average of five cold shots.

In summary, limited test data indicated that yaw life was extended in firing silicone-modified ammunition. However, gun stoppages and barrel deformation prevented definitive testing, and heavy coppering deposits were encountered in firing the modified ammunition. It appears that changes in rotating band material, ablator composition, or decoppering agent might be necessary to alleviate coppering in barrels firing large numbers of modified rounds.

---

* Gaging was limited to one land and one groove diameter measurement at each barrel station. In view of the large diameter changes observed, multiple measurements, which are more time consuming, did not appear warranted.

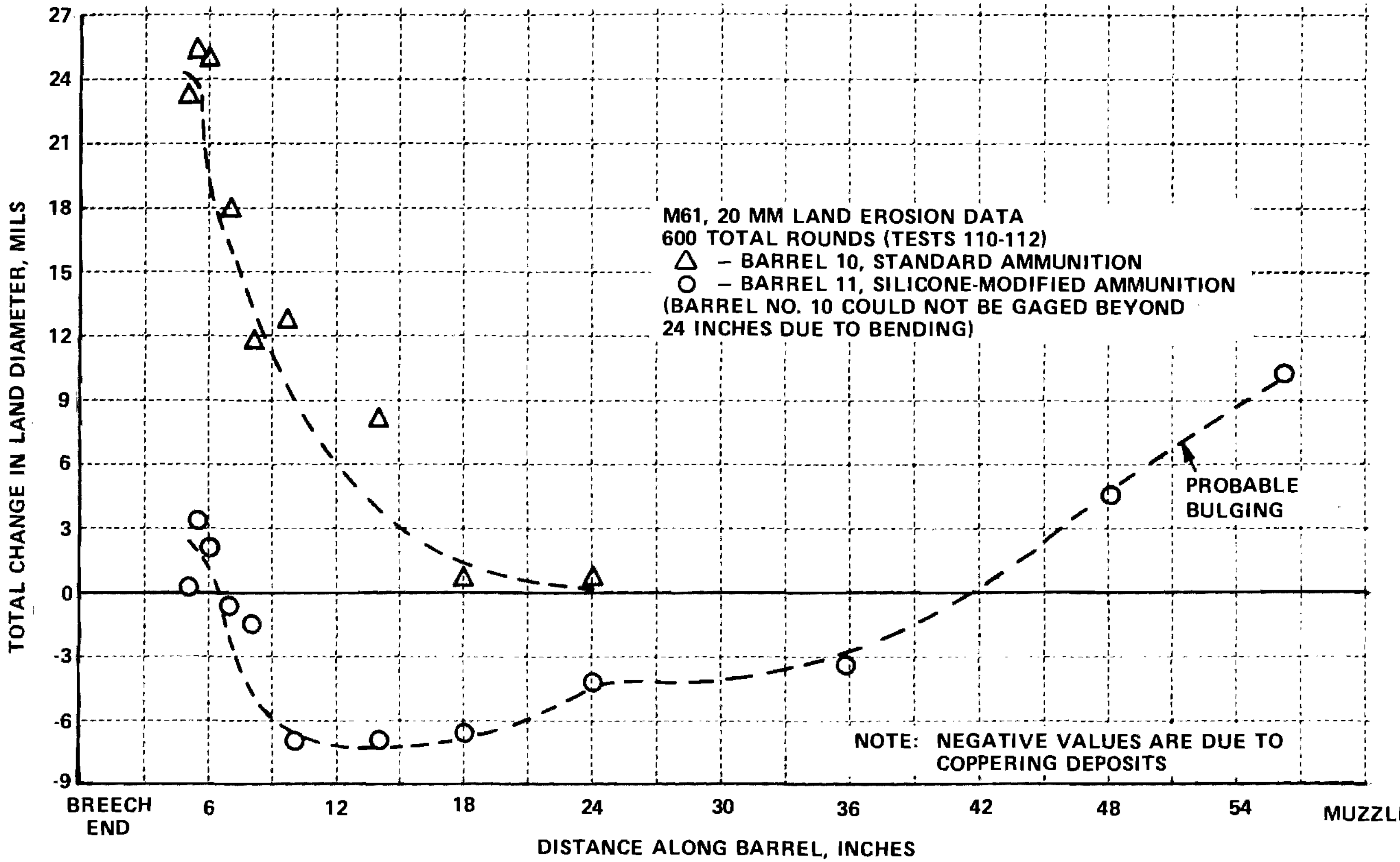


Figure 22. M61 Erosion Profiles – Land Diameter

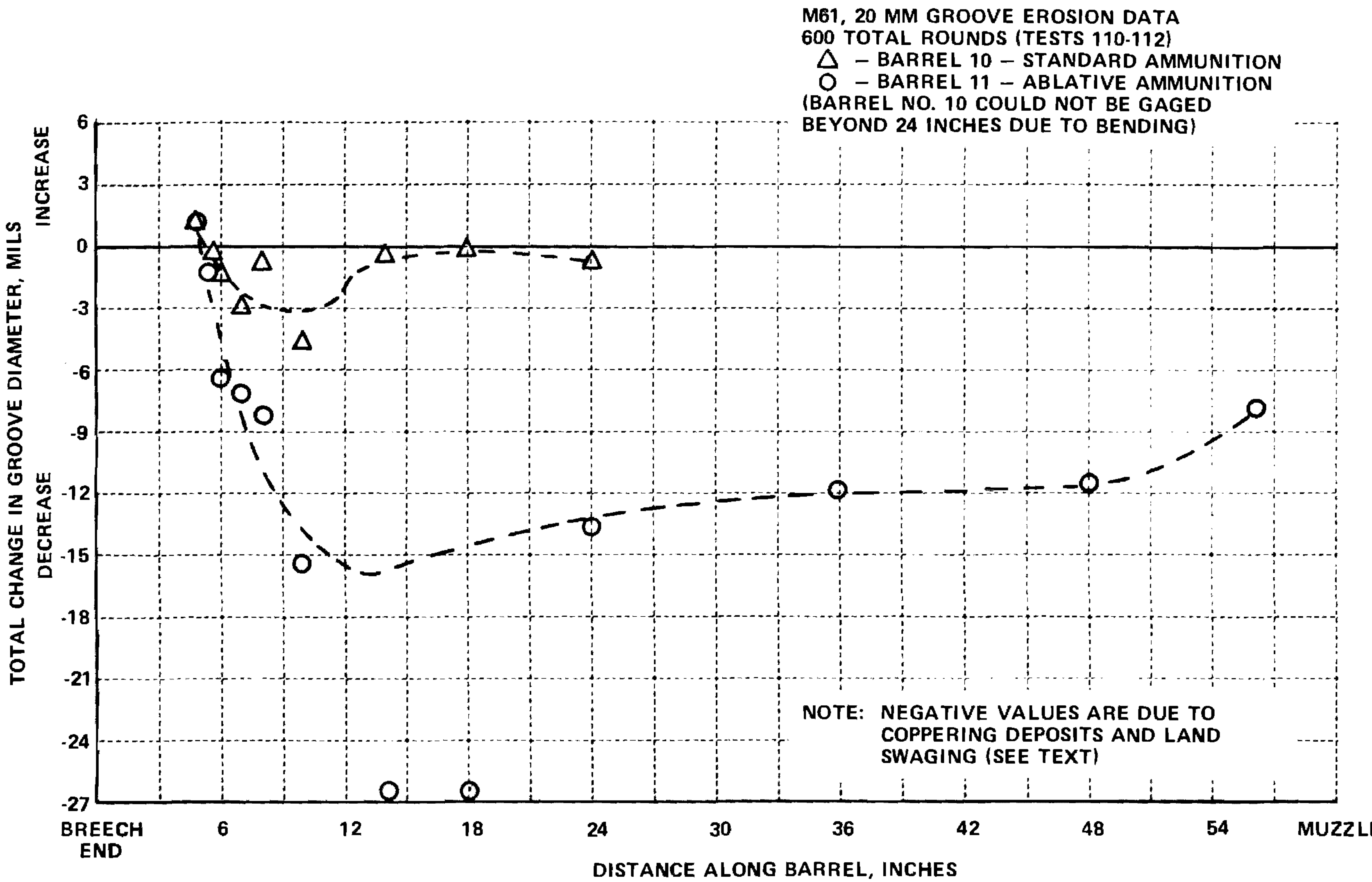


Figure 23. M61 Erosion Profiles – Groove Diameter

D. Temperature Instrumentation

Temperature measurements during test firing were taken from the ablative round barrel and one standard round barrel. Thirty-gauge chromel-alumel thermocouples were welded to each barrel at the positions shown in Figure 24. In view of the lesser barrel wall thickness relative to the M39 and the presence of mechanical stresses due to rotation during firing, it was decided that external surface thermocouples would be more reliable than in-wall types. Muzzle thermocouples failed due to blast effects.

Temperature data were taken from the revolving barrels with a slip-ring device in which the thermocouple circuits pass through silver slip rings which rotate with the gun barrels, to stationary graphite brushes which ride on the slip-rings and then to the recording device. The slip-ring drive extended through a hollow shaft attached to the rotating barrel assembly with a flange and set screws. The solid gun support at the back of the mount was replaced with a new block fitted with bearings to allow a shaft rotation and thermocouple feed-through. A plug-type thermocouple connector was employed at the front of the gun to facilitate barrel removal for gaging. Figure 20 shows the M61 mounted on the firing stand with the slip-ring assembly in place.

Thermocouple readout was accomplished with the multichannel light-beam oscillograph, allowing all ten thermocouple channels to be recorded on the same chart.

E. Temperature Data

Curves comparing temperature versus time and number of rounds fired, measured simultaneously for both barrels, are presented in Figures 25 through 29. It is noted that the data shown in these figures were obtained from a burst of 176 rounds. The dashed line indicates an extrapolation to 200 rounds. The temperature distribution along the length of each barrel at the instants 100 rounds and 200 rounds had been fired is presented in Figure 30. The accuracy of these data, determined on the basis of simultaneous measurements taken at the same point on a barrel, is estimated to be of the order of ±3 percent.

The data indicate that the ablative ammunition test was effective in reducing breech-end temperatures in the M61. Attendant cook-off benefits are discussed in Section VI of this report. Forward of the 15-inch barrel station, the data indicate essentially equal temperatures for ablative and standard ammunition.

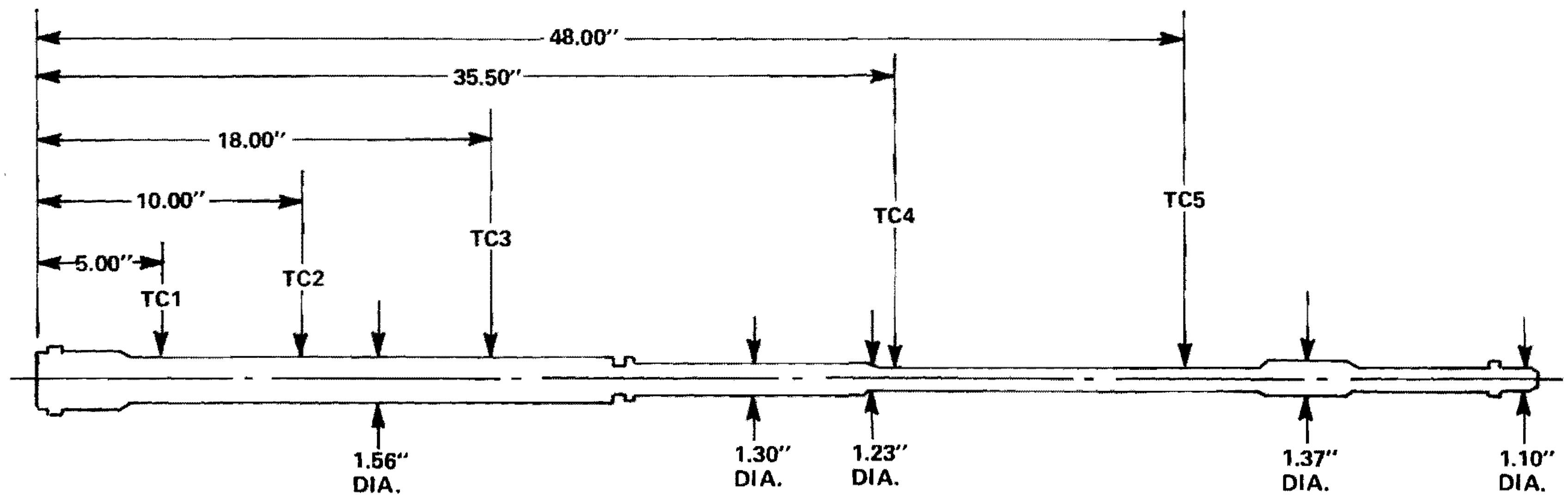


Figure 24. M61 Barrel Thermocouple Stations

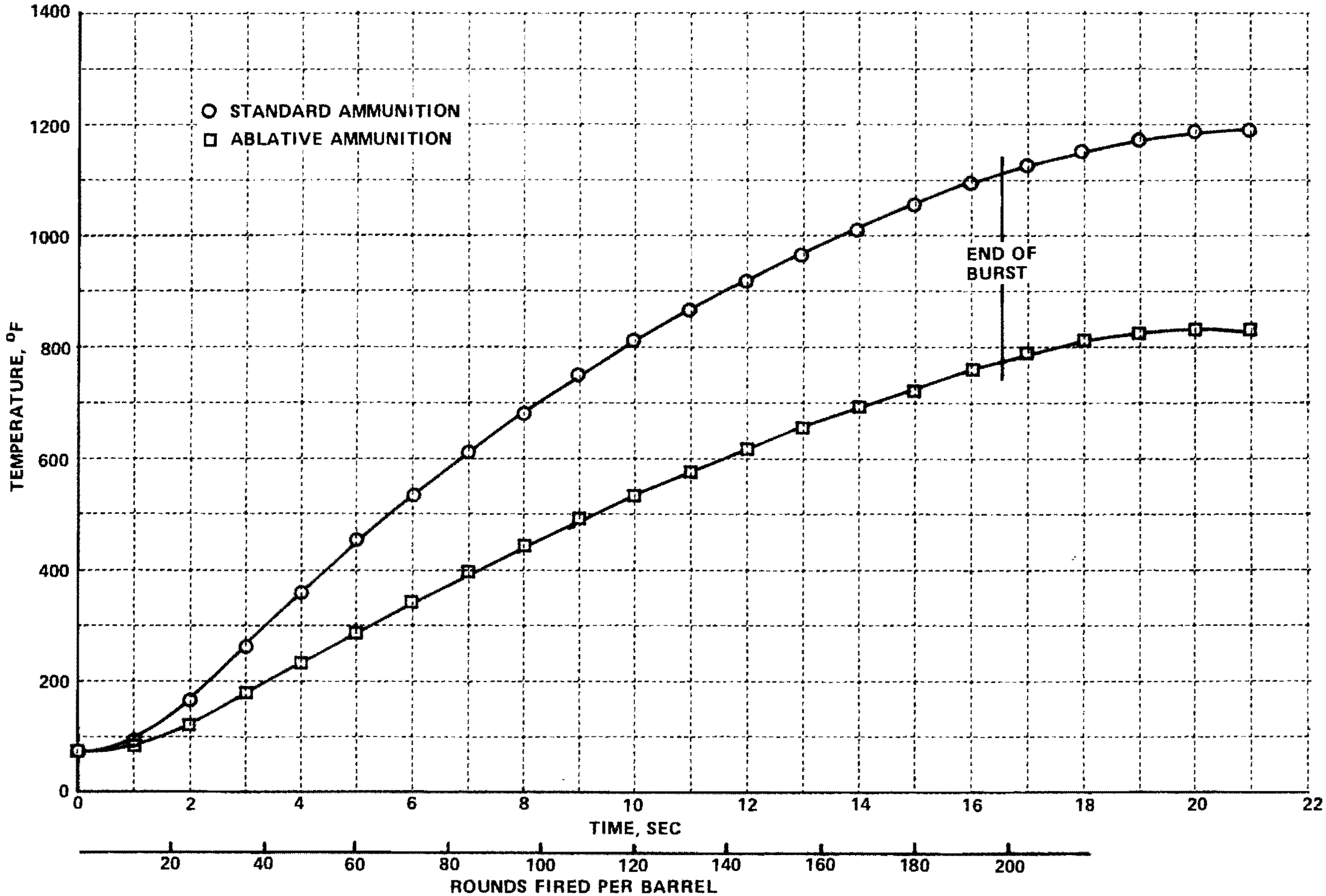


Figure 25. Measured M61 Barrel Temperatures 5 Inches From the Breech

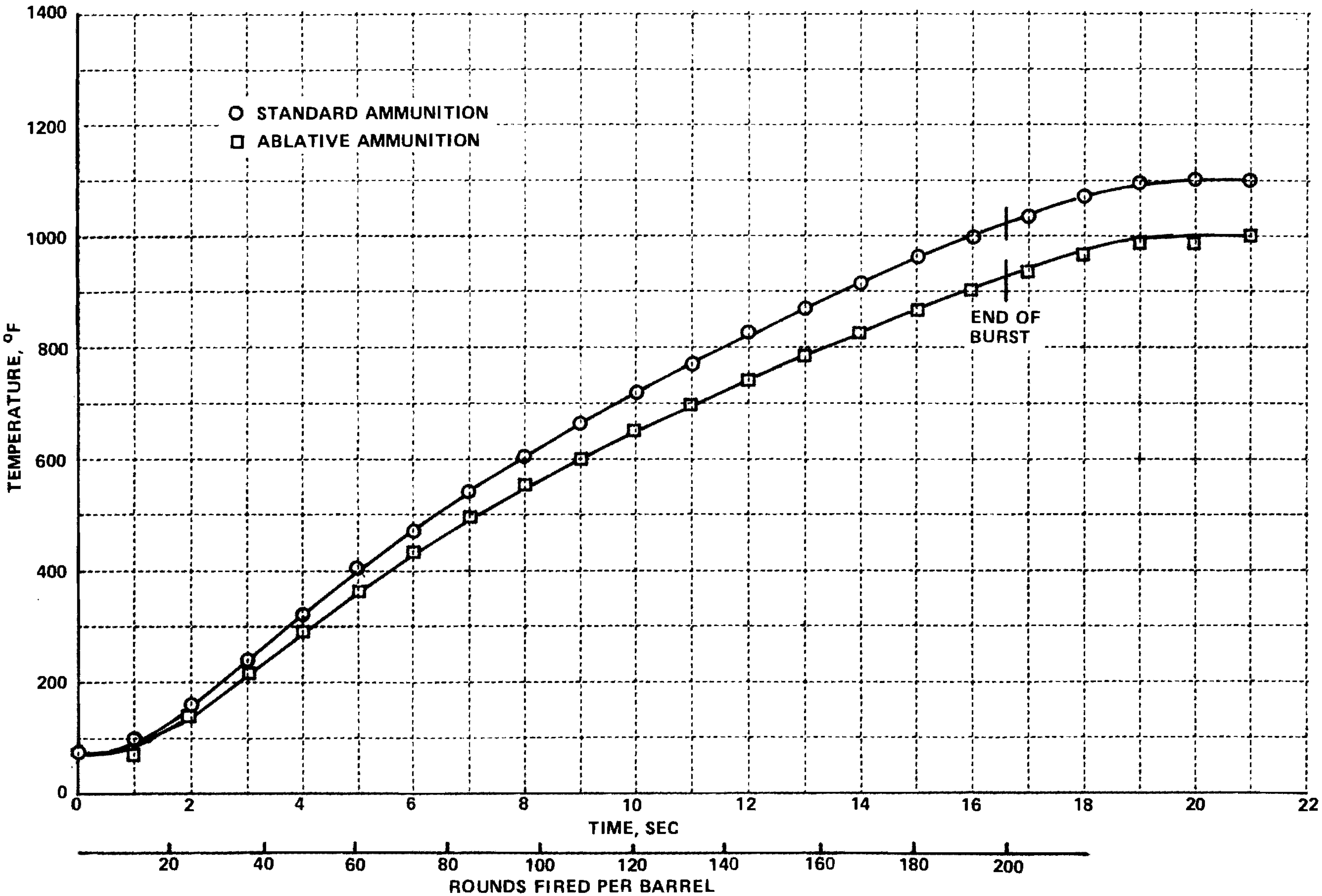


Figure 26. Measured M61 Barrel Temperatures 10 Inches From the Breech

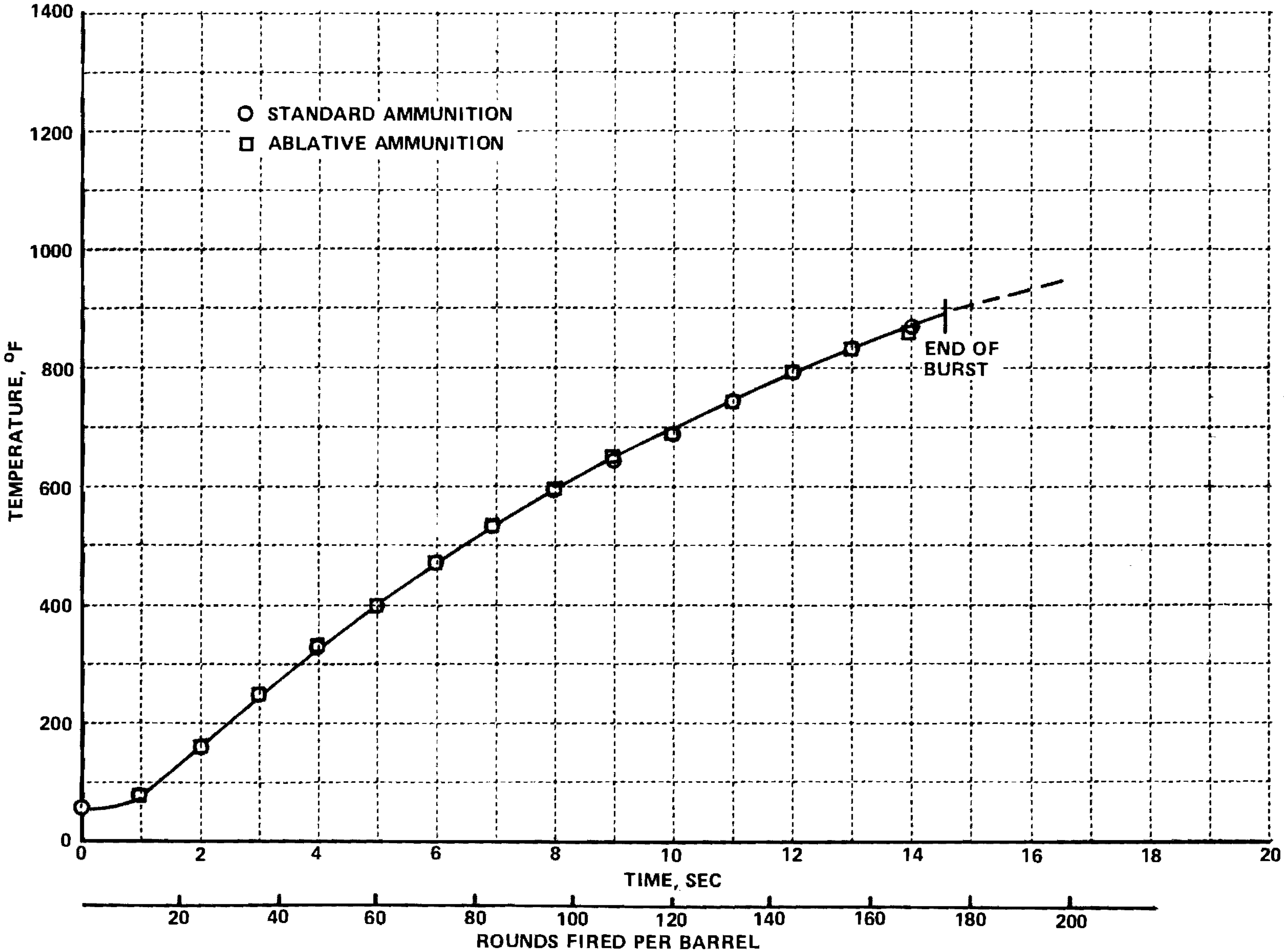


Figure 27. Measured M61 Barrel Temperatures 18 Inches From the Breech

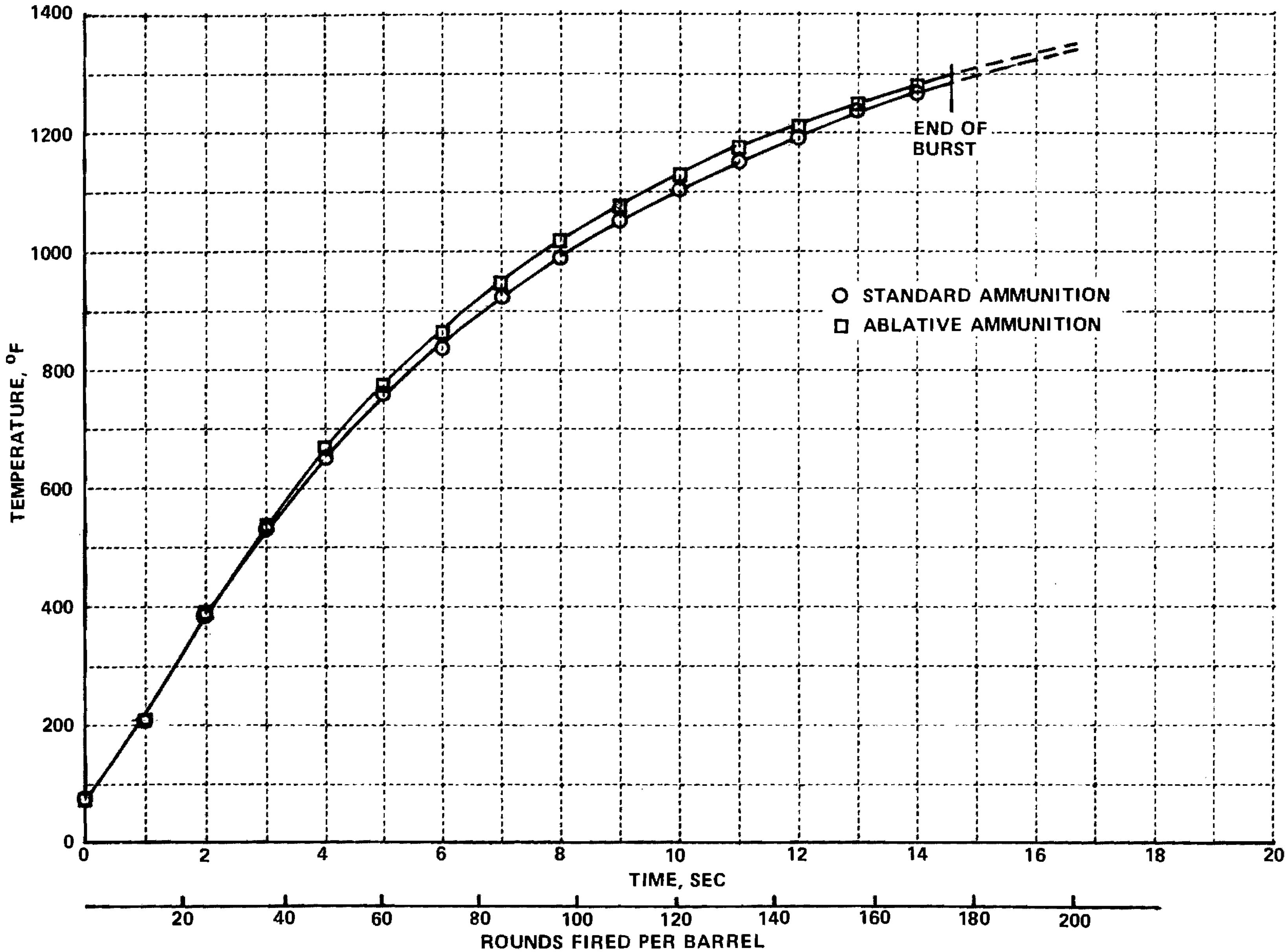


Figure 28. Measured M61 Barrel Temperatures 35.5 Inches From the Breech

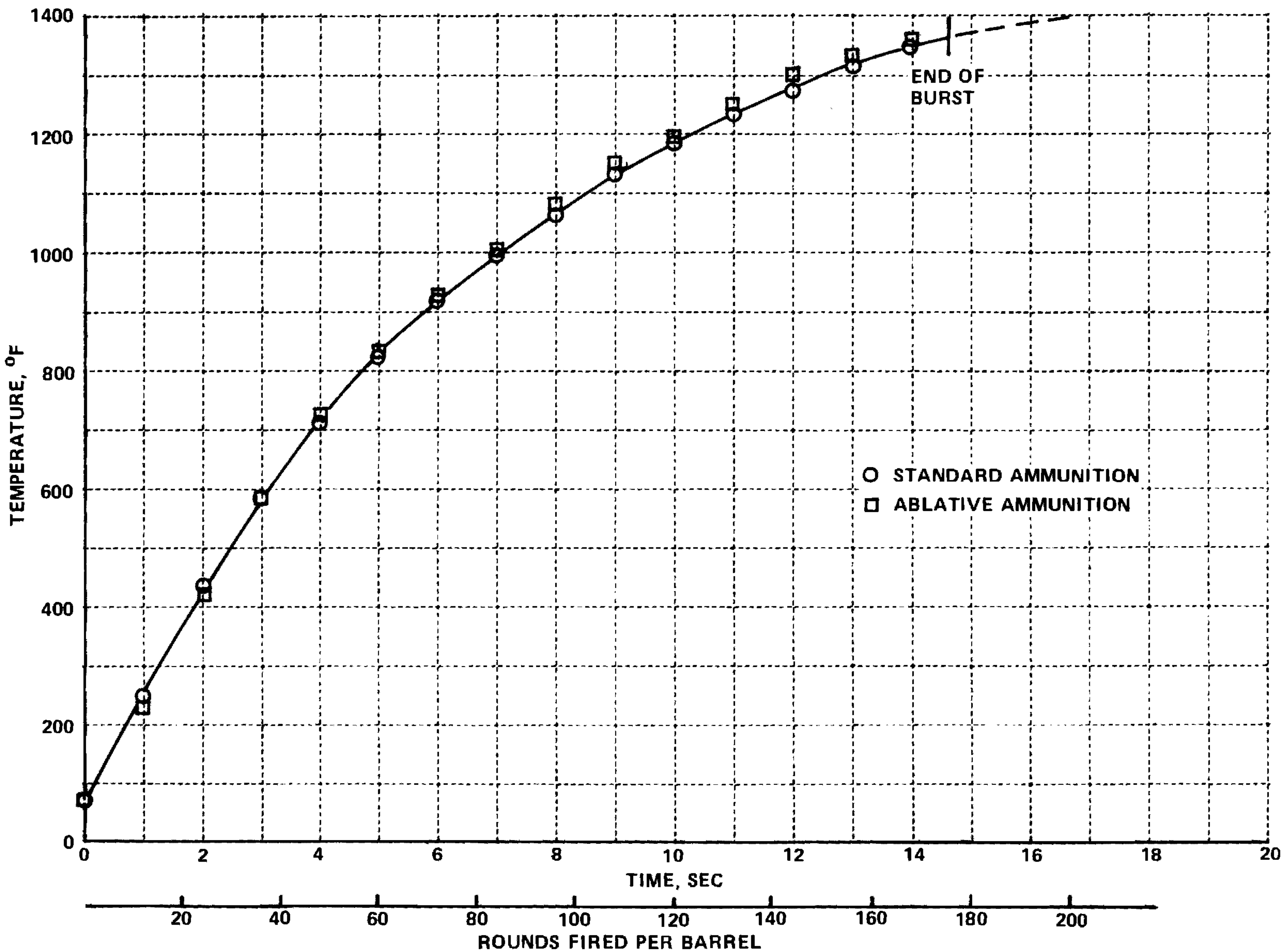


Figure 29. Measured M61 Barrel Temperatures 48 Inches From the Breech

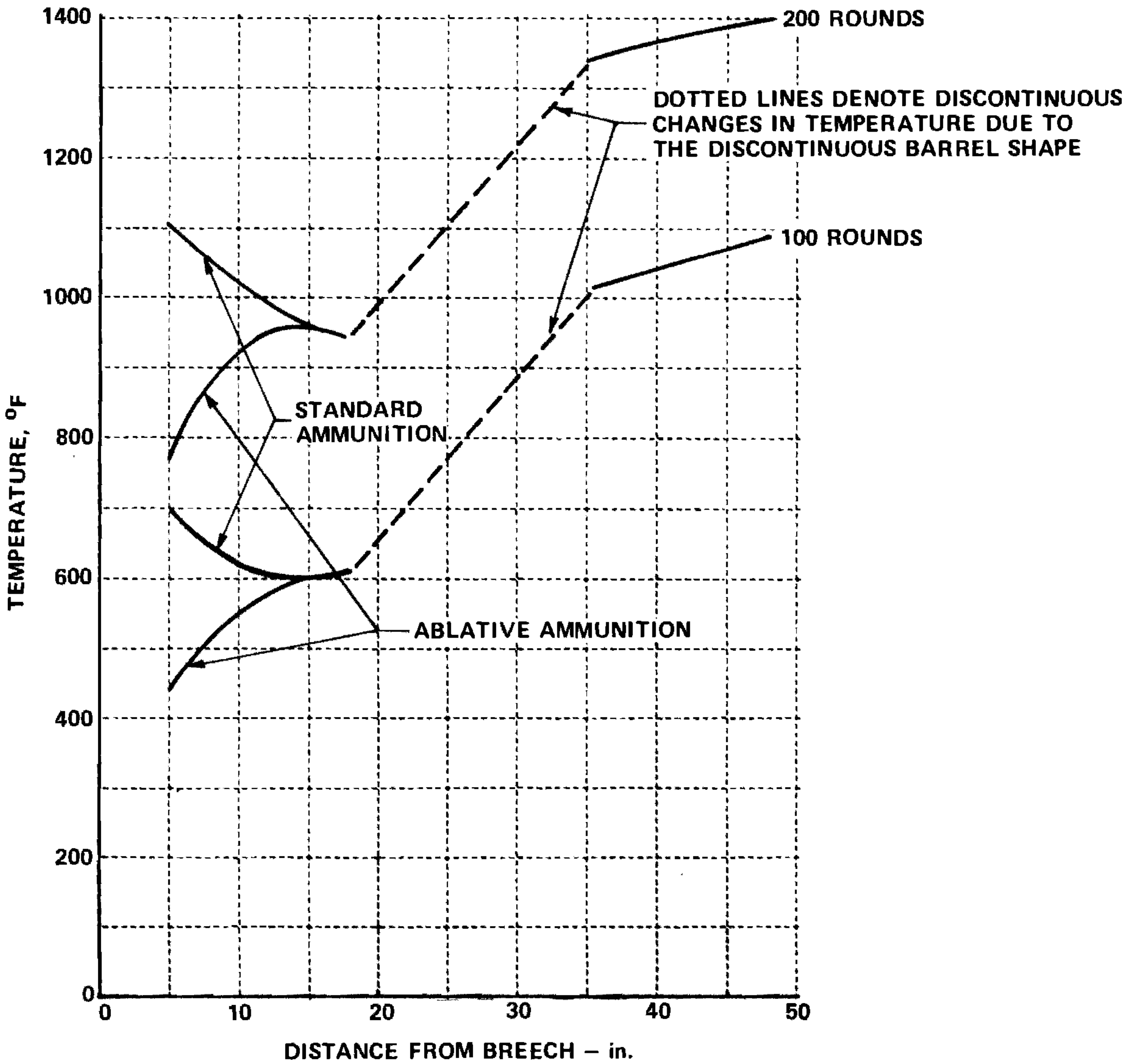


Figure 30. Variations of Temperature Along the Length of a Barrel

SECTION VI
COOK-OFF PERFORMANCE

Prime emphasis in the reported study program was directed to evaluation of the erosion and temperature behavior of weapons utilizing both standard and ablative ammunition. Specific cook-off tests were not conducted, but recorded temperatures indicate that substantial improvements in cook-off performance will accrue in weapons utilizing ablative ammunition. This is illustrated in the following interpretation of temperature data obtained for both the M39 and M61 weapons.

A. M39 Gun

Cook-off in the M39 weapon is primarily related to temperatures existing in the revolving drum. In this weapon, three rounds can be fully charged into the drum at the termination of a burst. The effects of cook-off vary depending upon the location of the cook-off round in the revolving drum. Should cook-off occur in the firing position, a projectile would be fired through the barrel with possible danger to friendly personnel or property. Cook-off in the first or second stage ram positions presents danger to the weapon, aircraft, or crew. Where HEI ammunition is used, cook-off of various explosive components may result in severe blast damage to the weapon, aircraft, or crew. Considerable test evaluation and analysis of the cook-off problem in the M39 weapon has previously been conducted for standard ammunition at this laboratory, and results are given in Reference 3. For the purposes of this discussion, some general information has been extracted where needed from this reference.

Drum temperatures recorded in this program for both standard and ablative ammunition are shown in Figures 14 and 15. It is clear by inspection of Figure 14 that considerable reduction in drum temperatures resulted through the use of ablative ammunition. Table IX illustrates the temperature rises and percentage reduction at the four thermocouple locations, C1, C2, C3, and C4, at 2 minutes* after 250-round bursts at full rate.

TABLE IX. DRUM TEMPERATURE RISES AFTER 250-ROUND BURSTS

Thermocouple Location	Temperature Rise Standard	Ablative	Percentage Reduction Using Ablative Ammunition
C1	235°F	110°F	53 %
C2	205	100	51
C3	168	90	47
C4	120	73	39

*Reference 3 indicates the 2-minute temperatures at C4 to be directly linked to cook-off. (See Figure 13(A), page 26 for thermocouple locations.)

Reference 3 indicated the mean drum temperatures to be given by thermocouple C4. Hence, a mean drum temperature rise reduction of at least 39 percent is shown by Table IX. Cook-off of round components depends upon existing drum temperatures after insertion of the round. Again, Reference 3 has related component cook-off to mean drum temperatures, and this is illustrated in Table X.

TABLE X. SUMMARY OF COMPONENT COOK-OFF

Component	Lowest Temperature at Thermocouple C4 with Cook-Off
Ball Propellant	290°F
Fuze Detonater	301
HEI Booster	321
HEI	356
Fuze Booster	364

The temperature rises at location C4 for 150- and 250-round bursts of standard ammunition (by inspection of Figures 14 and 15 at 2 minutes) are 77.5 and 120°F respectively. Thus, the average temperature rise per round for the standard ammunition is 0.5°F ± 4 percent. Based on this value and the reduction given in Table IX, the least number of rounds to cook-off of the various round components have been computed and are shown in Table XI for both standard and ablative ammunition.

TABLE XI. LEAST ROUNDS TO COOK-OFF

Round Component	Computed Number of Rounds to Cook-Off (70°F Ambient)	
	Standard	Ablative
Ball Propellant	440	720
Fuze Detonator	462	758
HEI Booster	502	826
HEI	572	940
Fuze Booster	588	965

The effects of ablative ammunition on cook-off in the M39 are observed to be substantial. The estimates shown in Table XI are conservative in that no account has been taken of the insulative effect of the ablator within the round. This effect would tend to increase the required mean drum temperature to cook-off of the ball propellant. Hence, burst length prior to cook-off conditions for the ablative ammunition will most likely be limited by the fuze detonator rather than the ball propellant. Further, the fuze detonator is acted upon more strongly by temperatures C1 and C2 where percentage reductions in temperature are greatest using ablative ammunition. One would expect, therefore, a greater than two-to-one increase in the burst length prior to cook-off using ablative ammunition in the M39 weapon.

B. M61 Gun

Cook-off in the M61 may occur in a hot weapon following a jam. The dangers of a cook-off in the M61 weapon are similar to those of the M39 weapon. Tests at Illinois Institute of Technology Research Institute (IITRI) (Reference 4) have indicated cook-off conditions to be reached in a single burst of 600 rounds. This conclusion was based upon barrel temperatures measured near the breech of the barrel in combination with measurements taken at the projectile base and fuze detonator of an instrumented round. Because ablative ammunition reduces breech temperatures significantly, the benefits of the use of ablative ammunition on cook-off performance will be large. Figure 31 shows the temperatures recorded at the 5-inch external barrel position as a function of time or number of rounds (solid lines). The estimated average barrel temperatures (dashed lines) are also shown. Three single points for this position taken from the IITRI data are included on this plot with a faired curve illustrating their trend. Because temperatures at this position have direct influence on cook-off due to their proximity to the fuze detonator, comparisons of number of rounds to cook-off can be made simply by comparison of these temperatures. In a burst of 600 rounds (the above indicated cook-off condition) or 100 rounds per barrel, the IITRI data show (Figure 31) a temperature of 900°F. Hence, it appears that a temperature of at least 900°F at the 5-inch position is required to produce cook-off of a fully chambered round. The cook-off point is designated on the figure with a circled "X". Data obtained in this program indicate slightly lower temperatures for the standard ammunition than obtained by IITRI, with an attendant increase in the number of rounds to cook-off as shown in Figure 31 (113 rounds/barrel). Slight extrapolation of the temperature data obtained for the ablative ammunition indicates an average temperature of 900°F to be achieved at about 228 rounds/barrel. Hence, one would not expect cook-off prior to this number of fired ablative rounds. Table XII summarizes total rounds fired to cook-off.

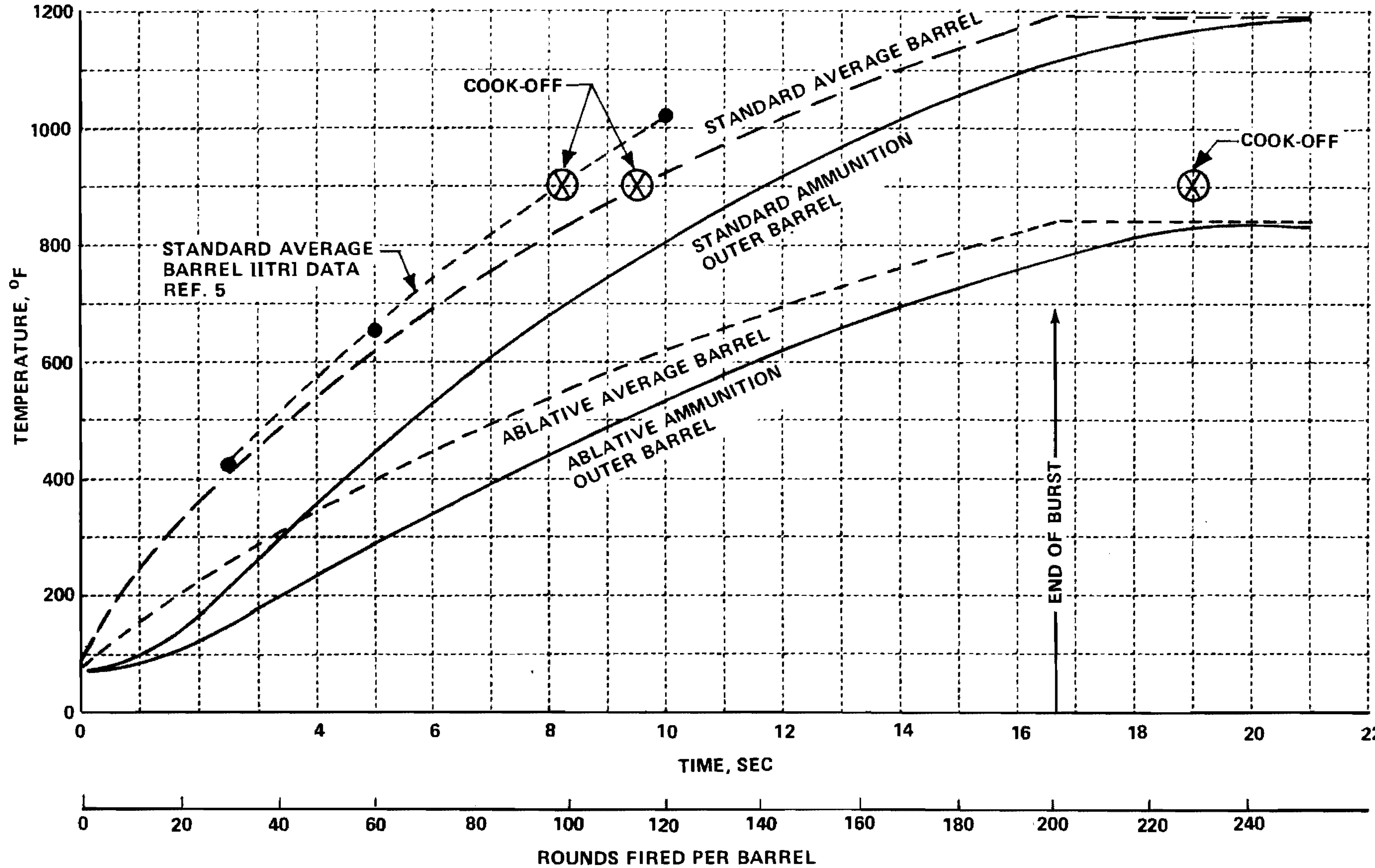


Figure 31. Barrel Temperatures at 5 Inches from the Breech Showing Cook-Off Limits

TABLE XII. COOK-OFF PERFORMANCE OF M61

	Allowable Burst Length to Cook-Off
IITRI Data - Standard Ammunition	600 rounds
CAL Data - Standard Ammunition	677
CAL Data - Ablative Ammunition	1370

A clear illustration of the effectiveness of ablative ammunition toward reducing potential cook-off hazards was obtained in one test firing at CAL. In this test, a total of 182 rounds per barrel had been fired through the weapon, followed by an improper feed and a jam. Two live rounds were fully inserted in their respective adjacent chambers, a standard and an ablative round. The standard round cooked-off within 17 seconds, whereas the ablative round did not cook-off. Cook-off of the standard round caused severe damage to the weapon, requiring major repair.

SECTION VII
SUMMARY AND CONCLUSIONS

While the burst firing tests completed in the M39 and M61 automatic cannons were hampered by gun stoppages, barrel bending, and other factors, tentative conclusions are drawn as follows.

A. Silicone-Modified Ammunition

1. It was possible to place 77 grains (5 cc) of gelled silicone behind the projectile of M55 A2 20mm ammunition without sacrificing ballistic performance. A 585-grain charge of conventional Olin WC 870 ball propellant was compressed moderately to make room for the silicone gel. Peak pressure was below 60,000 psi, and normal velocity (~3380 feet/second) was maintained. (Recent production Lot LC-24-345 standard rounds yielded a velocity of 3340 feet/second under identical conditions.)

2. The most promising ablator composition consisted of 94.5 percent 60,000 cstks viscosity dimethyl silicone and 5.5 percent (by weight) Cabosil fume silica, grade M-5. Silicone of 100,000 cstks viscosity performed similarly but was higher in cost.

3. Several thousand of the modified rounds were fired in long bursts in the M39 and M61 (Vulcan) cannons with no failures or stoppages attributable to the ammunition. It is concluded, therefore, that the modified ammunition can be fired in either gas-operated or electrically operated guns.

B. M39 Erosion

1. In the M39 20mm cannon, reproducible yaw failure was observed near the end of a single 250-round burst when firing unmodified (standard) ammunition. A barrel firing ablative ammunition failed at 1211 rounds, 799 of which were fired in ~250-round bursts. Therefore, the indicated life increase is more than 300 percent.

2. Barrel coppering was greater with the modified ammunition than with standard, and it appears that even larger life increases would result if coppering were reduced.

3. Barrels were gaged frequently during the testing, and bore enlargement was found to correlate generally with yaw performance.

C. M61 Erosion

1. In the M61 (Vulcan) cannon, no yaw failures attributable solely to erosion were obtained with either standard or silicone-modified ammunition. The rate of bore enlargement was greater in firing standard ammunition, but coppering and barrel bending interfered with precise gaging and gage data interpretation.

2. Coppering was much greater in the barrels firing modified ammunition. It appears possible that more extended firing would result in loss of projectile spin due to the coppering.

D. Eroded Barrel Studies

1. Electron microprobe examinations indicated that the coppering deposits in the barrels firing silicone-modified ammunition contained stringers or pockets of silicon-bearing material, probably SiO_2.

2. A chemical analysis of the coppering deposits by atomic absorption methods yielded a value of 2.49 percent for the silicon content, expressed as SiO_2.

3. It was inferred that a SiO_2 film (resulting from silicone decomposition) may form on the bore surface, cause increased friction, and result in increased wiping of the projectile rotating band material onto the bore.

E. Temperature Reduction and Cook-Off

1. Silicone-modified ammunition was found to reduce temperatures in the revolving drum of the M39 and in the breech end of both the M39 and M61 barrels.

2. It was shown by analysis that in the M39 the reduced drum heating would result in a 100-percent increase in the burst length safe against cook-off.

3. Similarly, it was predicted that, in the M61, aircraft carrying maximum ammunition complements of 1300 rounds per gun will be safe from cook-off. This includes the Lockheed F-104, Republic F-105, and the SUU-16/A Gun Pod. This represents more than double the number that can be fired with standard ammunition with equal cook-off safety.

(The reverse of this page is blank.)

APPENDIX I

METALLOGRAPHIC AND ANALYTICAL STUDIES

A. M61 Barrels

M61 barrels No. 10 and No. 11 (see Table VII) were sectioned lengthwise and transversely as indicated in Figure I-1. Barrel No. 10 had fired 600 standard rounds, and barrel No.11 had fired 600 silicone-modified rounds, all in simultaneous 200-round bursts. Barrel No. 10 failed by the yaw criterion at round 417, i.e., the seventeenth round of the third burst. Barrel No. 11 did not fail by yaw or velocity criteria but did become bent such that continued firing was not feasible. (The bending was believed to be due to barrel clamp binding.)

Each transverse section was mounted and polished to permit examination with the light microscope and the electron microprobe analyzer. Since the identification and comparison of coppering deposits in each barrel were of chief interest, the polished sections were not chemically etched to reveal the grain structure of the steel. It was feared that etchants might attack the coppering deposits, altering their appearance or composition.

Electron microprobe images were examined in detail to determine the association of silicon (from the silicone ablator) with coppering deposits. In addition, bore surfaces were examined with the microprobe for evidence of copper or silicon diffusion into the barrel steel.

Low-magnification views of the bore surfaces of both the M61 and M39 barrels tested in this program are presented in Figures I-2 and I-3. All of the M39 barrels tested were chrome plated, and all of the M61 barrels were unplated.

1. Bore Condition Near Origin of Rifling - Section A-A

(a) Standard Ammunition Barrel

At section A-A, located 2.0 inches from the origin of rifling, barrel No. 10 showed complete loss of the rifling lands (Figure I-4), and at higher magnification (Figure I-5), radial cracks were revealed. Visual inspection of the eroded bore after each burst suggested that the heat-softened lands tended to be swaged or flattened down rather than being stripped off. Cracking and heat-checking in unplated bores have been linked by previous investigators to multiple austenite-martensite transformations, caused by thermal cycling of the bore surface.

A section adjacent to that pictured in Figure I-5 was analyzed qualitatively with an electron microprobe instrument for comparison with the barrel firing silicone-modified ammunition. Figure I-6 provides orientation to the area microprobed, believed to be the root of a rifling land. The same area at 325X magnification is shown by ordinary light microscopy in Figure I-7 and by

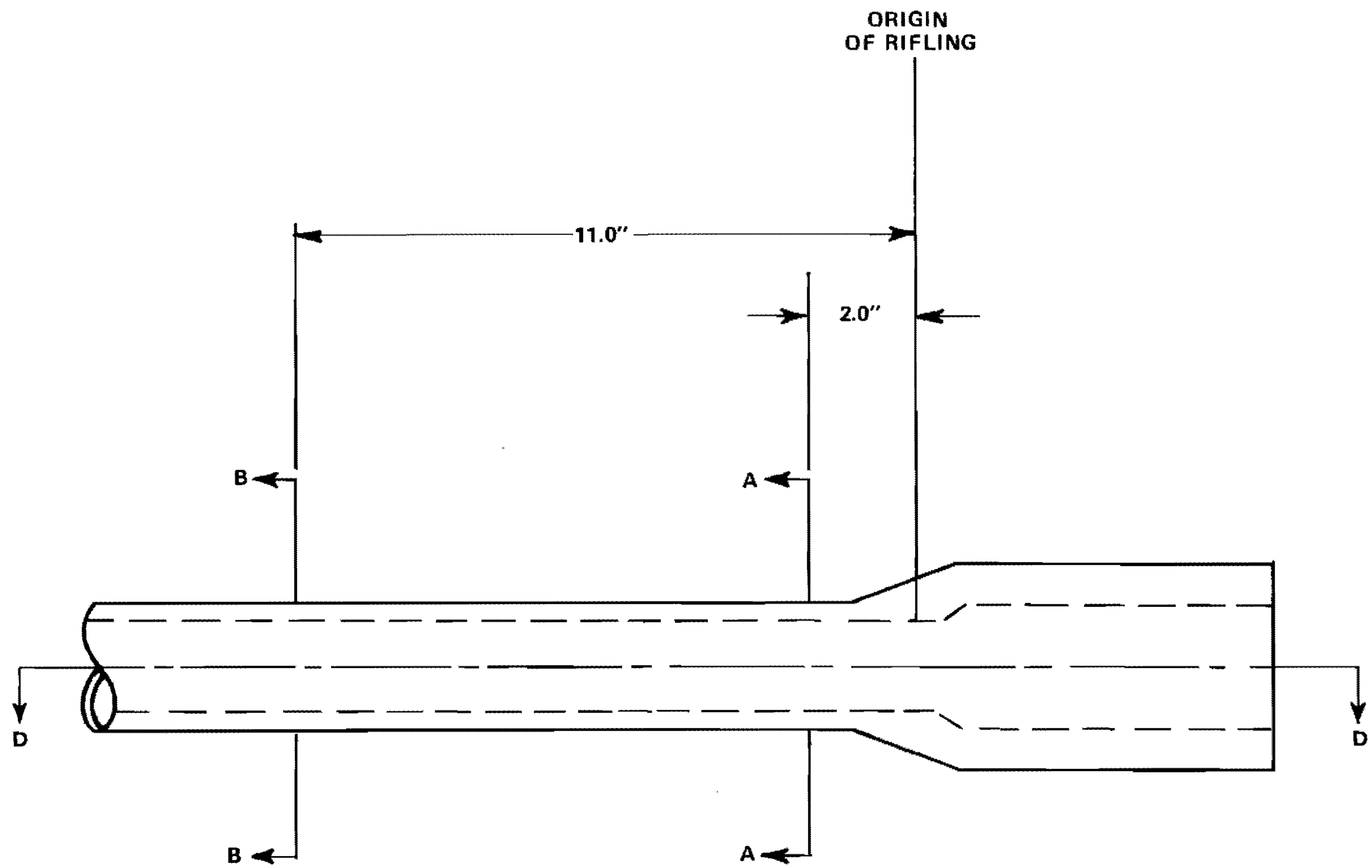


Figure I-1. M61 Barrel Section Locations

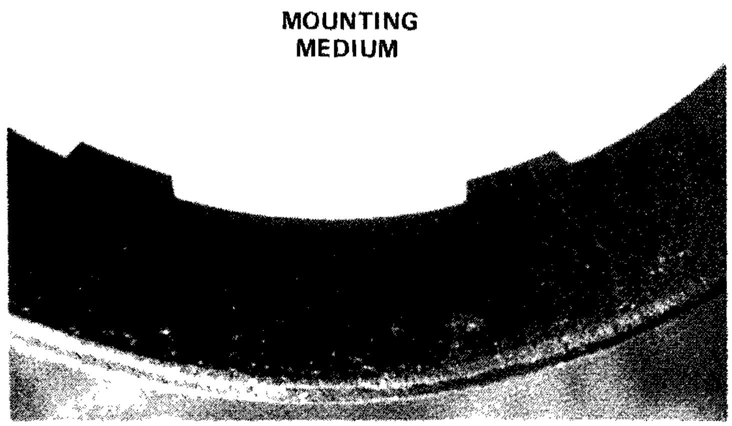


Figure I-2. M61 Bore Surface In New Condition (8X)

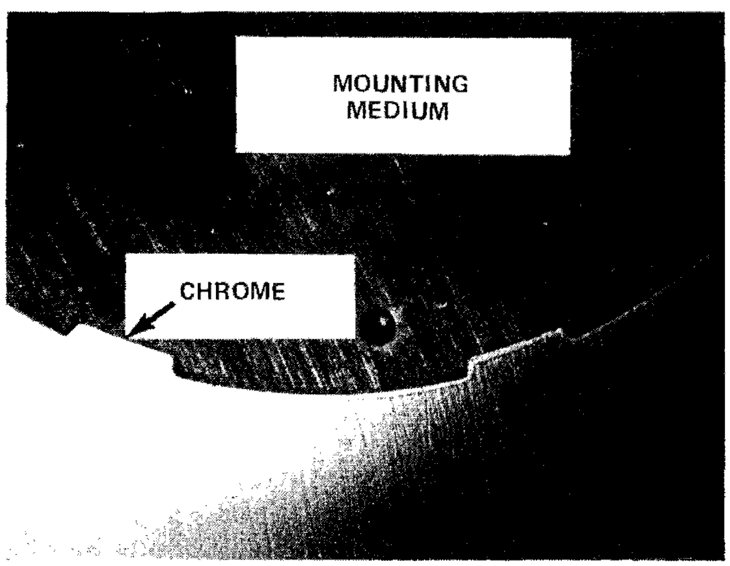


Figure I-3. M39 Bore Surface In New Condition (8X)

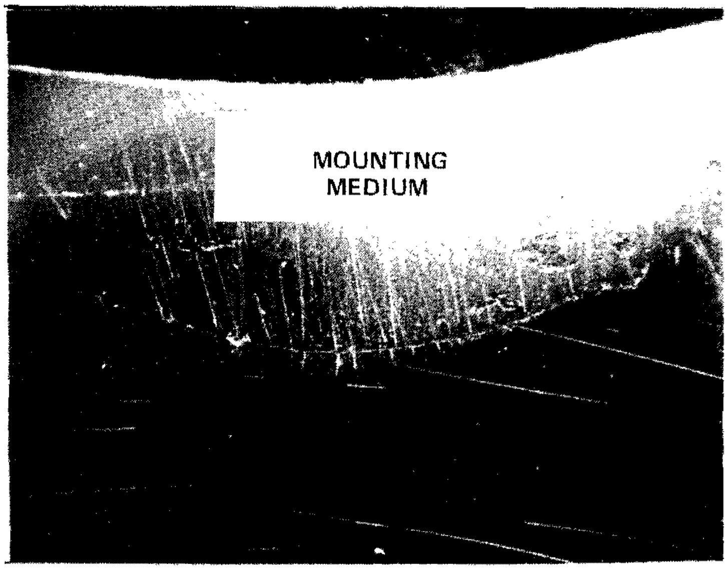


Figure I-4. Section A-A, M61 Barrel No. 10, Standard Ammunition (8X)

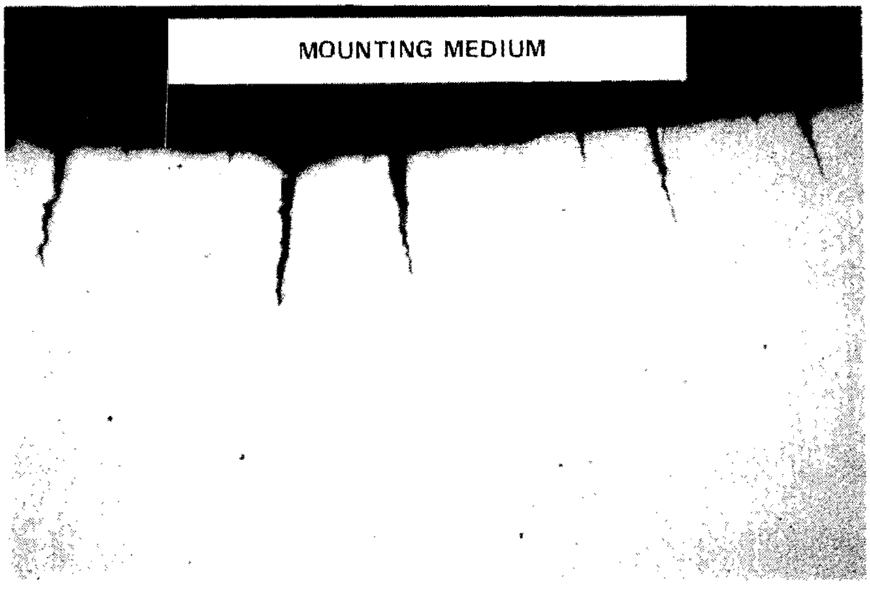


Figure I-5. Section A-A, Barrel No. 10, Standard Ammunition (50X)

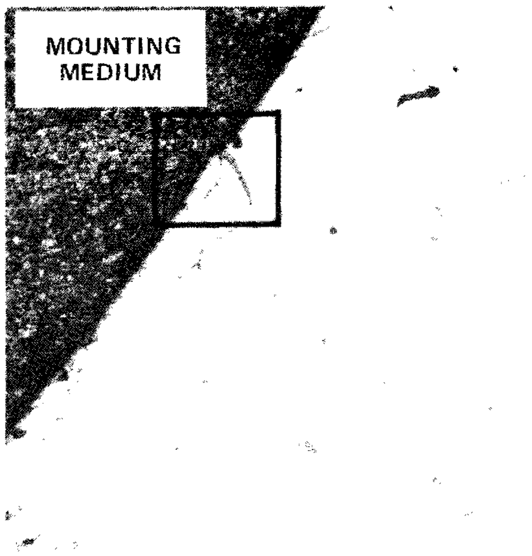


Figure I-6. Section A-A, Barrel No. 10, Standard Ammunition (50X)

Figure I-7. Area Outlined In Fig. I-6 (325X)

Figure I-8. Copper Microprobe Image Of Area of Fig. I-7 (325X)

Figure I-9. Silicon Microprobe Image Of Area Of Fig. I-7 (325X)

the copper x-ray image from the electron microprobe in Figure I-8. In images of this type, the intensity of whiteness is related to the concentration of the specified element, i. e., the light areas in Figure I-8 contain copper.

The silicon image of the same area (Figure I-9) indicated that no silicon was associated with the coppering present in the crack. (It will be shown later that silicon is present in the coppering deposits in barrels firing ablative ammunition.) The few intense white spots on the bore surface in Figure I-9 are believed to be silicon carbide particles embedded during specimen preparation on silicon carbide abrasive paper. The rather high white-background intensity in images such as Figure I-9 is due to the high instrument sensitivity setting required in searching for trace amounts.

Other areas of the same section (not photographed) indicated that coppering was very slight on the bore surface but was prevalent in cracks. Zinc microprobe images, an example of which is shown later, indicated that the coppering was essentially the same in composition as the copper-zinc alloy rotating band from which it came.

(b) Silicone-Modified Ammunition Barrel

At section A-A, the rifling appeared to be in very good condition, as shown in Figures I-10 and I-11. The contrast with the standard ammunition barrel (Figures I-4 and I-5) was marked. Slight to moderate coppering was present, particularly along the sides of each land, as illustrated in Figures I-12 through I-15. With respect to silicon, Figure I-15 and other areas examined (but not photographed) indicated clearly that most of the silicon present was in the form of stringers or pockets of silicone or silica, intimately associated with the coppering deposits. However, certain areas of the deposit, such as that near the center of Figures I-13 through I-15, were relatively free of silicon.

Considering that the silicon-bearing material survived high bore temperatures as well as sectioning and polishing procedures, it was considered probable that the material was silica (SiO_2) rather than the original methyl silicone compound employed as the ablative material. It was known that methyl silicone compounds can oxidize to minute silica particles at high temperatures.

In summary, somewhat more coppering was present near the breech end of the barrel firing silicone-modified ammunition than in the standard ammunition barrel, and the silicone was inferred to be the cause of this increased coppering. However, the protective effect of the silicone-modified ammunition on the rifling, at section A-A, appeared to far outweigh any deleterious effect of coppering.

2. Bore Condition at Section B-B

(a) Standard Ammunition Barrel

Section B-B is located 11 inches from the origin of rifling. Barrel No. 10 exhibited some land deformation and coppering, as shown in Figures I-16

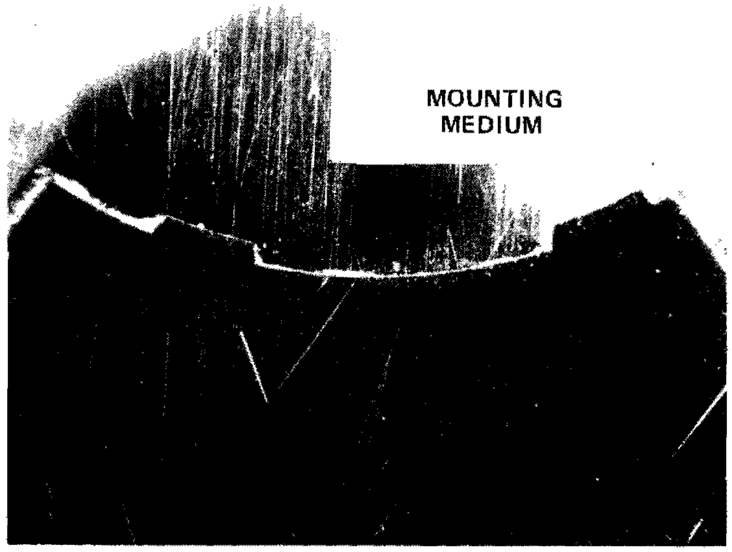


Figure I-10. Section A-A, M61 Barrel No. 11, Ablative Ammunition (8X)

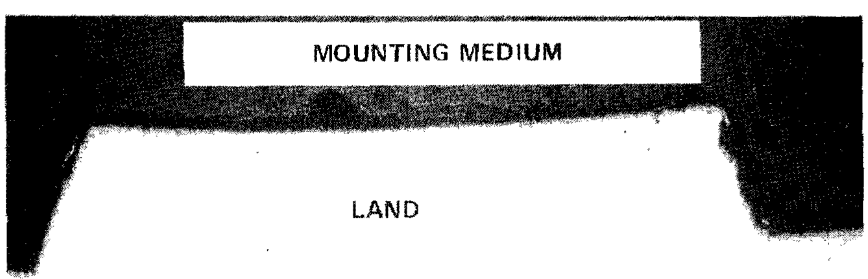


Figure I-11. Section A-A, Barrel No. 11 (50X)

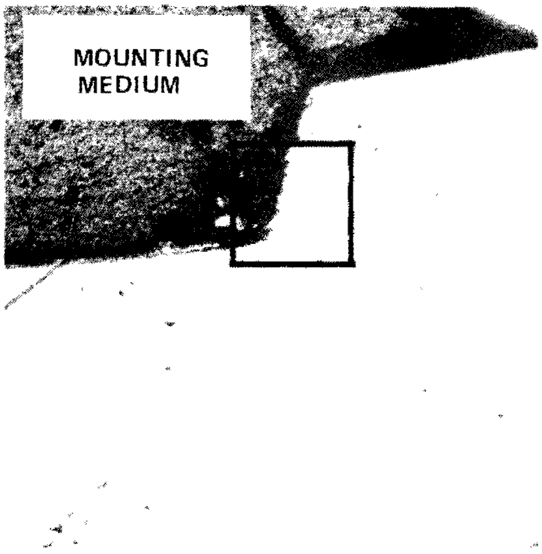


Figure I-12. Section A-A, Barrel No. 11, Ablative Ammunition (50X)

Figure I-13. Area Outlined In Fig. I-12 (325X)

Figure I-14. Copper Microprobe Image Of Area Of Fig. I-13 (325X)

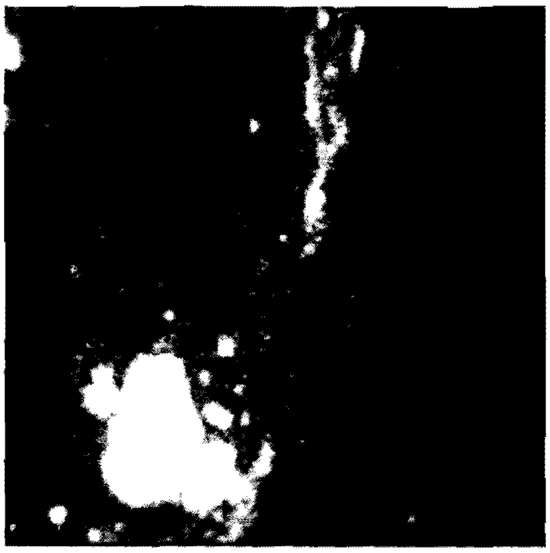


Figure I-15. Silicon Microprobe Image Of Area Of Fig. I-13 (325X)

through I-20. The iron microprobe image (Figure I-19) was examined closely for copper diffusion into the steel, but none was found. Coppering deposits were rather homogeneous with respect to copper distribution (Figure I-20) and were essentially devoid of silicon. Traces of aluminum were found (Figure I-21), probably traceable to specimen polishing with alumina.

(b) Silicone-Modified Ammunition Barrel

At section B-B, barrel No. 11 showed heavy coppering and land deformation. Figures I-22 through I-27 illustrate conditions at the edge of a land, with Figure I-26 showing a rather even distribution of zinc in the coppering deposit, as was the case in all coppered areas. Stringers of silicon-bearing material were prominent in the coppering, as shown in Figure I-27.

By visual examination, section B-B was typical of the bore cross-section from a point about 4 inches from the origin of rifling to one approximately 24 inches forward. Near the muzzle, neither barrel No. 10 nor No. 11 was coppered, but the barrel firing standard ammunition (No. 10) was more severely deformed. Since coppering was of primary interest, no muzzle sections were prepared in this study.

B. M39 Barrels

1. Standard Ammunition Barrels

M39 barrels firing standard ammunition failed in one 250-round continuous burst. Sections analogous to those of Figure I-1 were prepared and examined, with results typified by Figures I-28 through I-30. It was noted that bore damage was much more severe in the first 10 inches of the tube than at other points.

Electron microprobe analysis by visual examination of copper, zinc, silicon, chrome, and iron images revealed no features qualitatively different from those illustrated previously in M61 barrels.

2. Silicone Ablative Ammunition Barrels

Since the only M39 barrel fired with silicone-modified ammunition was tested to yaw failure at 1211 rounds, no direct comparison of a barrel which had fired modified rounds with a barrel which had fired an equal number of standard rounds was possible. Visual examination of barrel sections indicated that coppering was similar to that in M61 barrels but possibly less severe due to the presence of chrome plating.

C. Chemical Analysis

A sample of the coppering deposit scraped from an M61 barrel was subjected to atomic absorption analysis for silicon content. The finding was 1.16 percent Si (silicon), which is equal to 2.49 percent expressed as SiO_2 (silica). The procedure employed did not discriminate between Si and SiO_2.

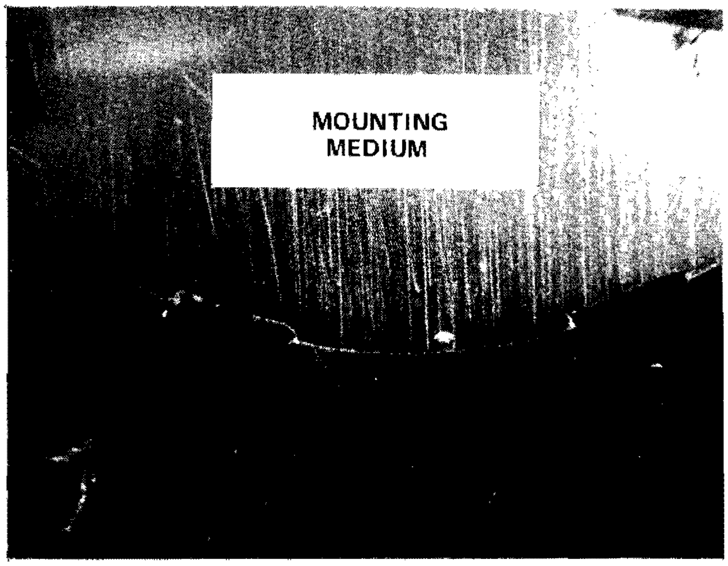


Figure I-16. Section B-B, M61 Barrel No. 10, Standard Ammunition (8X)

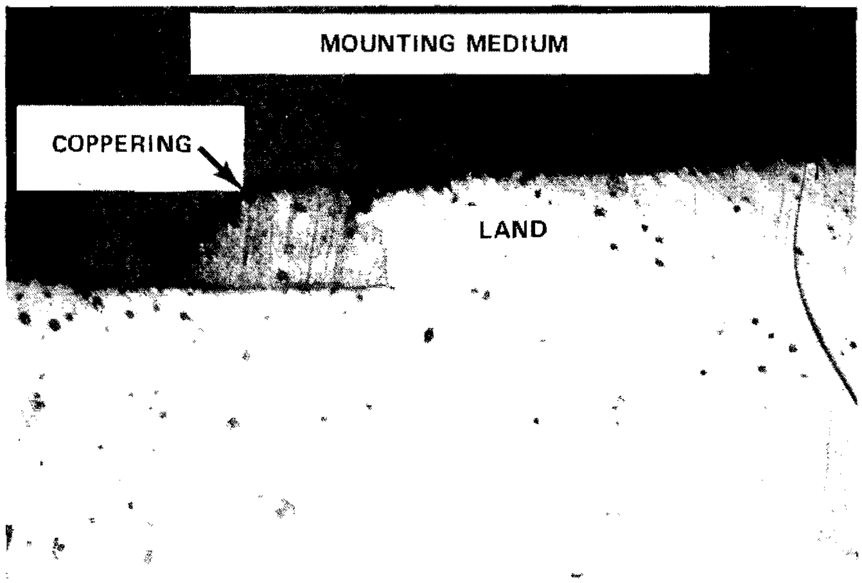


Figure I-17. Section B-B, Barrel No. 10 (50X)

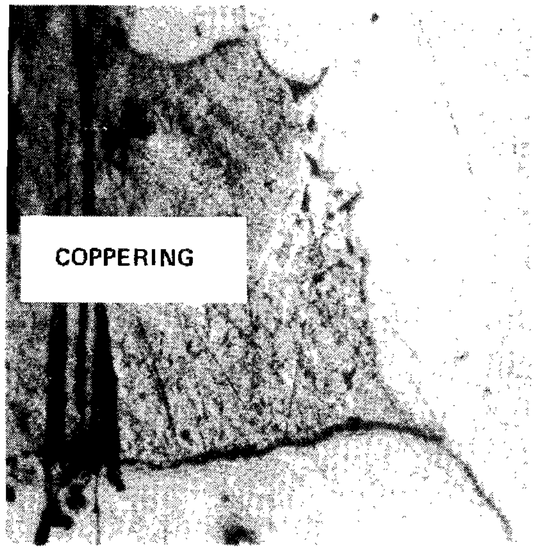


Figure I-18. Section B-B, Barrel No. 10, Standard Ammunition (325X)

Figure I-19. Iron Microprobe Image Of Area Of Fig. I-18 (325X)

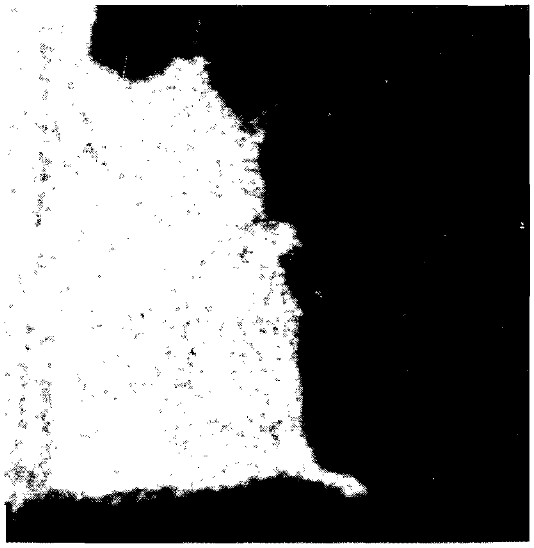


Figure I-20. Copper Microprobe Image Of Area Of Fig. I-18 (325X)

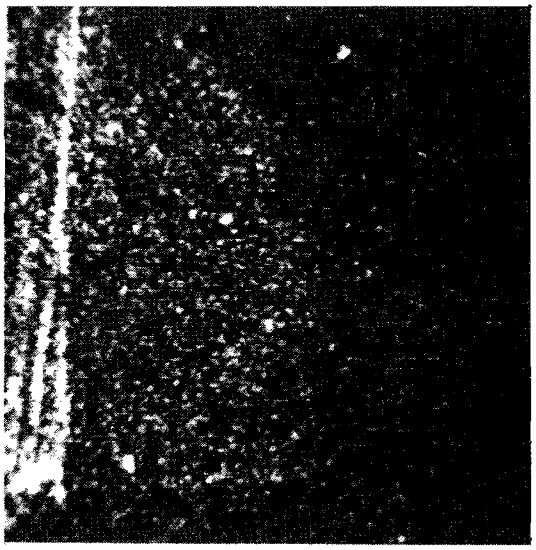


Figure I-21. Aluminum Microprobe Image Of Area Of Fig. I-18 (325X)

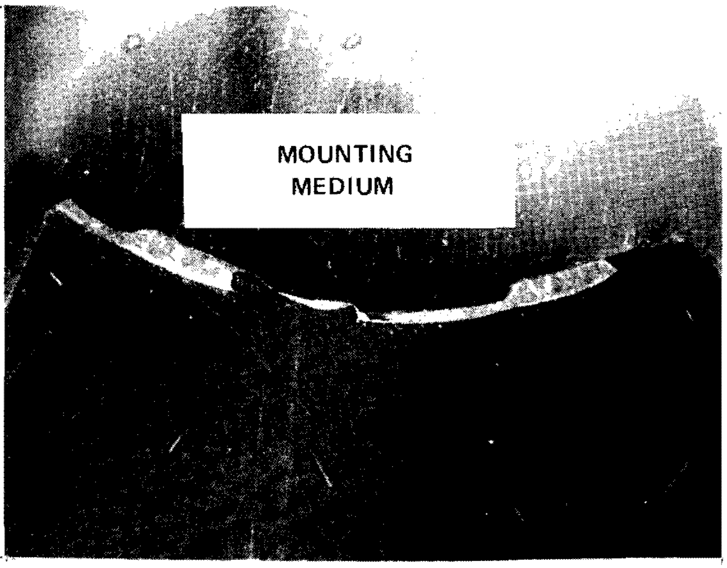


Figure I-22. Section B-B, M61 Barrel No. 11, Ablative Ammunition (8X)

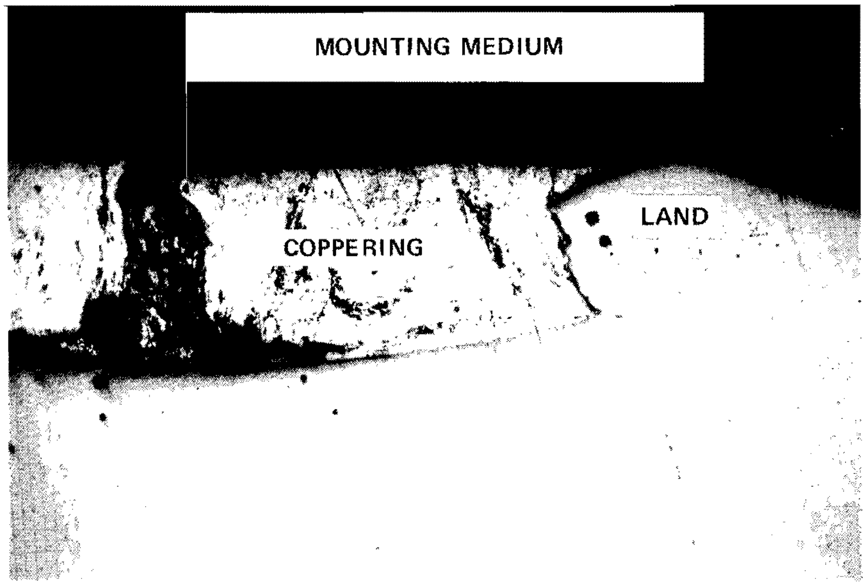


Figure I-23. Section B-B, Barrel No. 11 (50X)

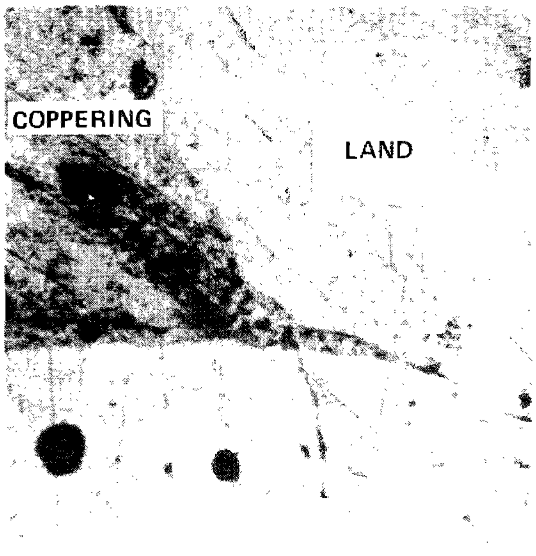


Figure I-24. Section B-B, Barrel No. 11, Ablative Ammunition (325X)

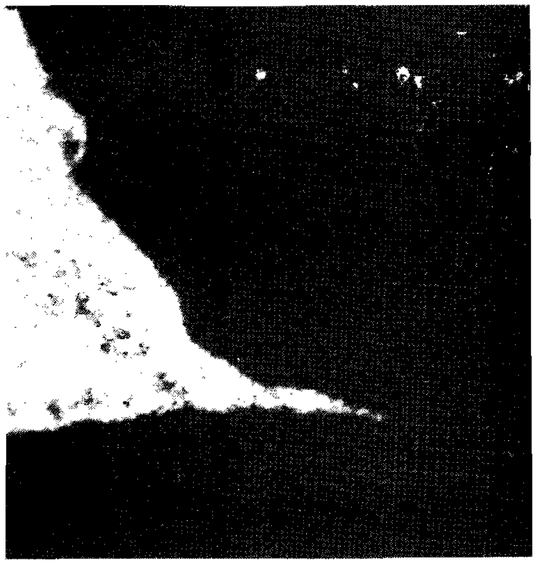


Figure I-25. Copper Microprobe Image Of Area Of Fig. I-24 (325X)

Figure I-26. Zinc Microprobe Image Of Area Of Fig. I-24 (325X)

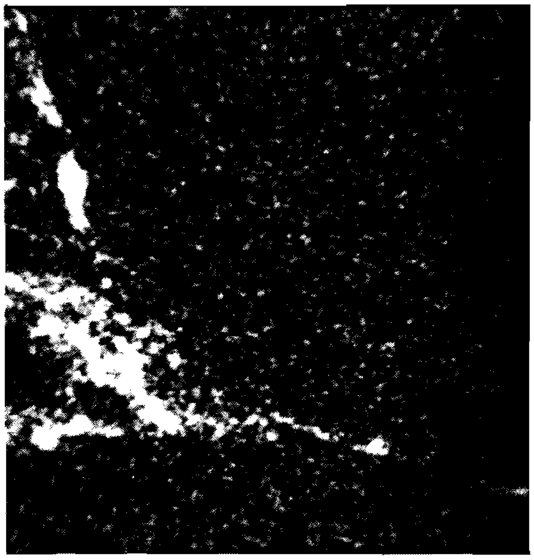


Figure I-27. Silicon Microprobe Image Of Area Of Fig. I-24 (325X)

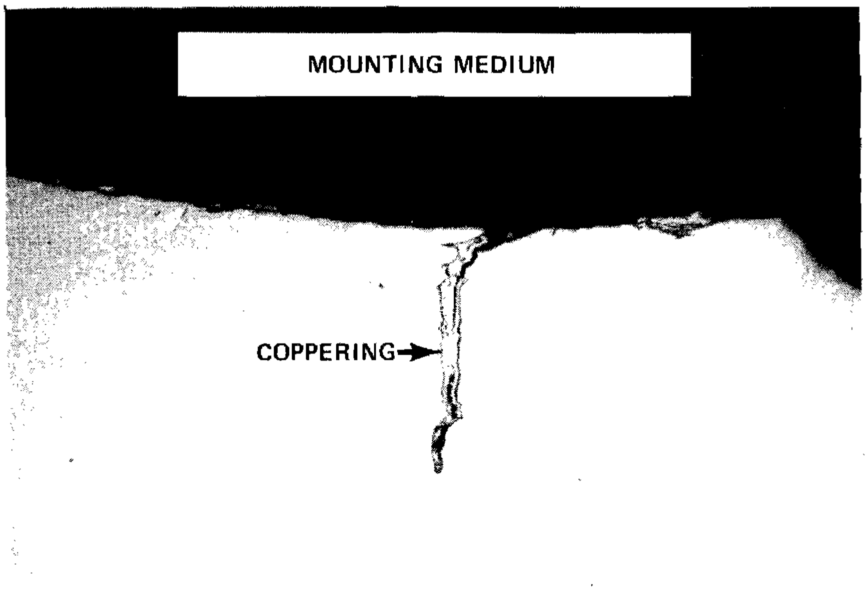


Figure I-28. Section A-A, M39 Barrel No. 4, Standard Ammunition (50X)

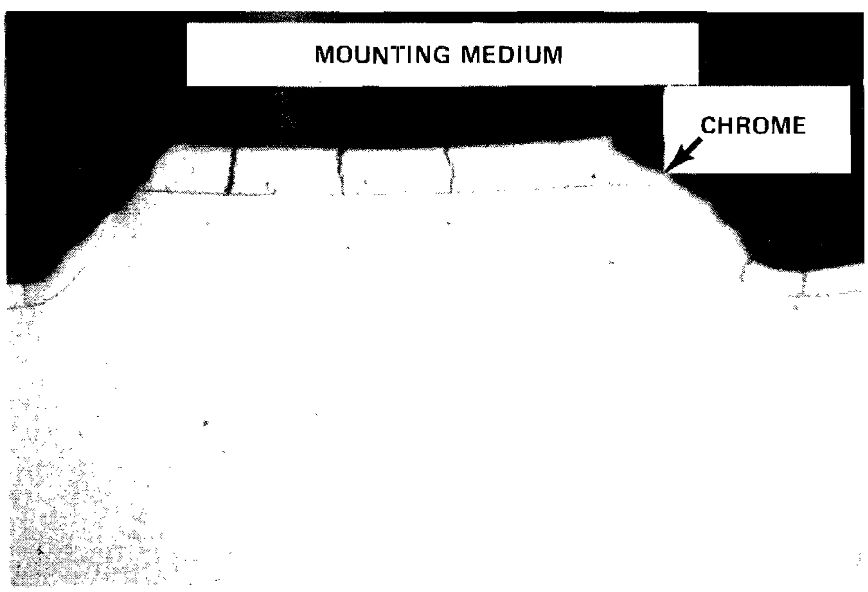


Figure I-29. Section B-B, M39 Barrel No. 4, Standard Ammunition (50X)

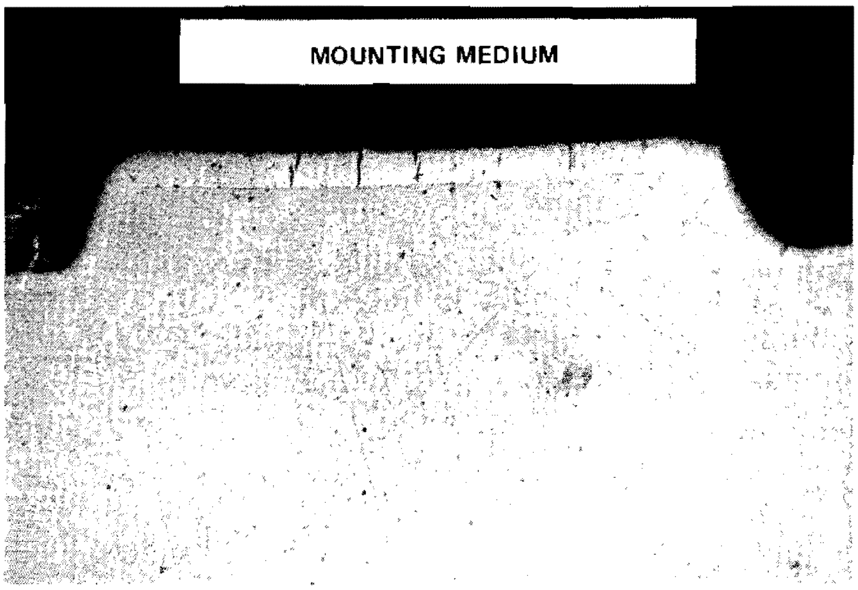


Figure I-30. Section Near Muzzle, M39 Barrel No. 4, Standard Ammunition (50X)

Microprobe images suggested a silicon content somewhat higher than 1.16 percent. However, it should be noted that no attempt was made to employ quantitative procedures in the microprobe examination; high instrument sensitivity settings were employed to bring out the presence of silicon in the coppering deposit.

D. Discussion

It was not possible to discern from the examinations and analyses the exact cause of increased coppering in the barrels firing silicone-modified ammunition. Considering, however, the established presence of silicon in the coppering deposits, it appears probable that a film of silica is deposited on the bore with each shot, and the silica acts to increase friction with the rotating band such that more band material is wiped onto the bore. It is also possible that the silica film interferes with the normal action of the tin dioxide decoppering agent incorporated in the propellant.

These indications suggest that the coppering might be reduced by incorporating a solid-film high-temperature lubricant in the silicone or by increasing the amount of decoppering agent in the propellant.

REFERENCES

1. Adams, D. E., Brown, W. R., and Vassallo, F.A., "Design Studies of the XM140 Barrel, Volume II," CAL Report No. GA-2446-Z-1, October 1967.

2. Fisher, R., "Erosion Test of Production and Special Barrels for the Gun, Automatic, 20mm, M39," APG Report TS-3-3047-41, April 1958.

3. Sterbutzel, G. A., "M39 Cook-Off Summary Report," CAL Report No. GA-948-C-49, January 1960.

4. Vodvarka, F. J., "Investigation of Gun Heating and Ammunition Cook-Off in the 20mm Gun, M61," IITRI Project No. K161, Final Report, July 1961.

(The reverse of this page is blank)

INITIAL DISTRIBUTION

HQ USAF (RDQRM)	2	AFATL (DL)	1
HQ USAF (SAMID)	1	AFATL (DLB)	1
HQ USAF (XOXFCM)	1	AFATL (DLY)	1
HQ USAF (XOOW)	2	AFATL (DLOSL)	2
HQ USAF (RDPA)	1	AFATL (DLDG)	10
AFSC (IGFG)	1		
AFSC (DLTW)	1		
AFSC (SDWM)	1		
ASD (ENVS)	1		
AFFDL (FBS)	1		
TAC (DMW)	1		
TAC (DRFM)	1		
TAC (DMAM)	1		
WRAMA (MMEBL)	1		
AFWL (DOGL)	1		
AUL/AUL-LES-70-239	1		
CHIEF OF R&D (CRDAM)	1		
AMSWEREW	1		
AMXRD-AS	1		
AMXRD-AA	1		
AMXRD-DB	1		
AMXRD-BTL	1		
FRANKFORD ARS (LIB,H1300)	1		
SMUPA-RT-S, BLDG 59	1		
NAV AIR SYS CMD (AIR 350B)	1		
USNWL (CODE TR)	1		
USN WEA CNTR (CODE 753)	2		
57 FTR WG (FWOA)	1		
CHEM PROP INFO AGENCY	2		
BATTELLE MEMORIAL INST	1		
AMCRD-BN	1		
TAC FTR WPNS CNTR (CRCD)	1		
DDC	2		
CINCUSAFE (DMW)	1		
CINCUSAFE (OA)	1		
CINCPACAF (DMWXE)	4		
USAFTAWC (AY)	1		
CORNELL AERO LAB	20		
HQ PACAF (IGY)	1		
ASD (ENYS)	1		

(The reverse of this page is blank)

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Cornell Aeronautical Laboratory, Inc., Buffalo, New York 14221	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP ---

3. REPORT TITLE

PERFORMANCE OF 20MM ABLATIVE AMMUNITION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report - September 1970 to December 1971

5. AUTHOR(S) (First name, middle initial, last name)

W. R. Brown D. J. Sudlik
E. B. Fisher F. A. Vassallo

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1971	84	4

8a. CONTRACT OR GRANT NO. F08635-70-C-0119	9a. ORIGINATOR'S REPORT NUMBER(S) CAL No. GM-3010-D-1
b. PROJECT NO. 670A	
c. Task No. 10	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. Work Unit No. 023	AFATL-TR-71-164

10. DISTRIBUTION STATEMENT

~~Distribution limited to U. S. Government agencies only; this report documents performance tests of 20mm ablative ammunition; distribution limitation applied December 1971. Other requests for this document must be referred to the Air Force Armament Laboratory (DLDG), Eglin Air Force Base, Florida 32542.~~

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Available in DDC	Air Force Armament Laboratory Air Force Systems Command Eglin Air Force Base, Florida 32542

13. ABSTRACT

M55 A2, 20mm ammunition was modified by placing five cubic centimeters of gelled dimethyl silicone compound between the propellant charge and the projectile. The function of the silicone was to reduce barrel heating and erosion by coating the bore surface, forming an insulative and ablative shield against the hot propellant gases. Several thousand silicone-modified and standard rounds were fired in thermocouple-instrumented M39 and M61 (Vulcan) cannons. Very substantial reductions in heat input to the revolving drum of the M39 and the rear portion of the M61 barrel were effected, and cook-off analyses indicated a 100-percent increase in the burst length safe against cook-off in both the M39 and the M61. Erosion reduction and yaw-life increase were demonstrated in 250-round burst firing of the M39. In the M61 barrels, which were unplated, heavy coppering deposits with the modified ammunition and barrel bending interfered with rational erosion testing, but bore enlargement near the origin of rifling was decreased by the modified ammunition. Eroded and coppered barrels were sectioned and examined by metallographic and electron microprobe techniques. Ballistic performance was maintained in the modified ammunition, and no failures or gun stoppages attributable to the ammunition were experienced.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ablative ammunition						
Silicone fluid ablator						
Barrel erosion						
Ammunition ballistics						
Barrel heating						
M39 erosion						
M61 erosion						
Cook-off						